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The Feasibility of Utilizing Solid Wastes for Building Materials Executive Summary

Eben Research Systems, Silver Spring, Md

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio

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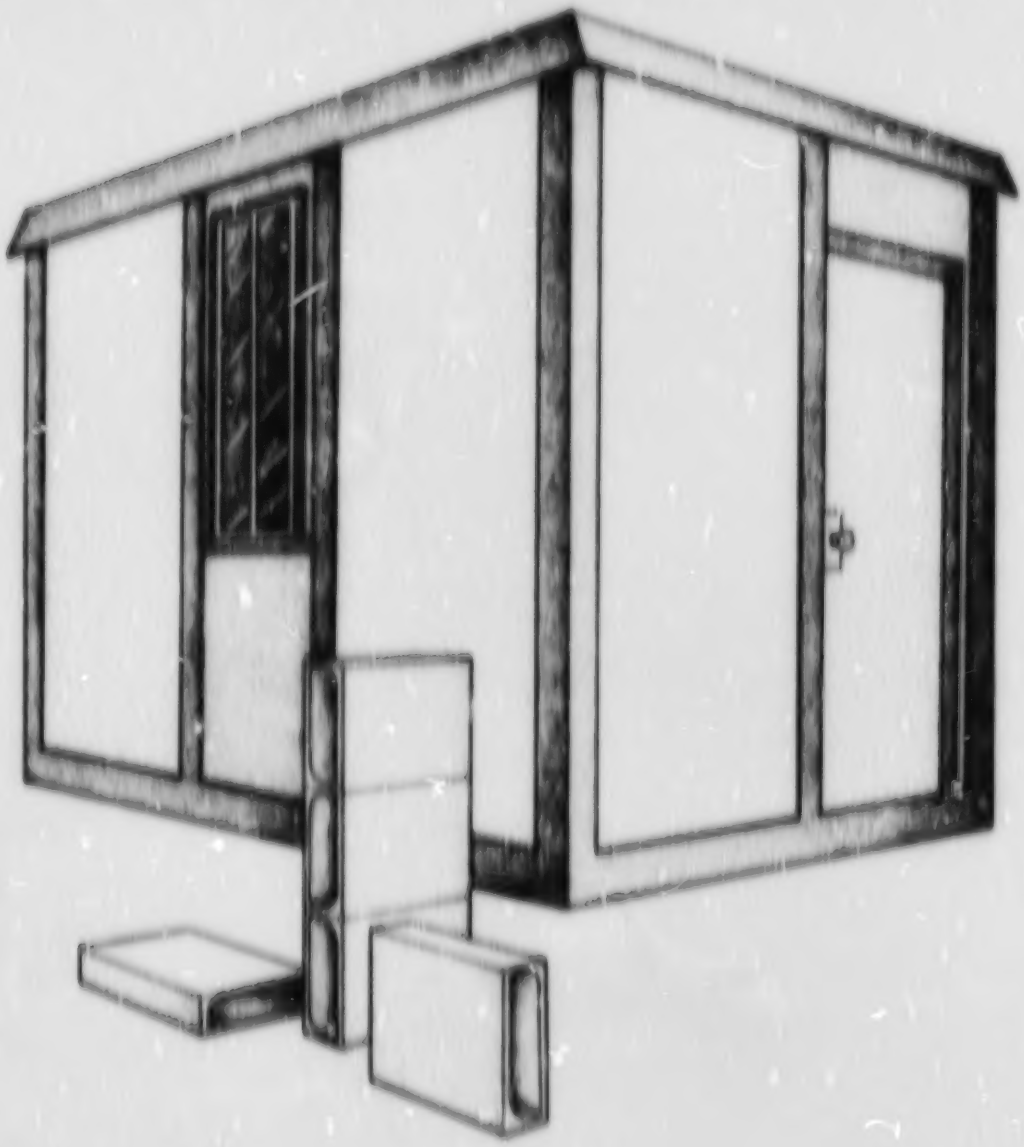

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THE FEASIBILITY OF UTILIZING SOLID WASTES FOR BUILDING MATERIALS

Executive Summary

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Contract Nos. 68-03-2460-1
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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This research has resulted in materials that can provide economical housing for the homeless and help to solve solid waste disposal problems.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

ABSTRACT

This report is an executive summary of a two-phase study by Material Systems Corporation initiated to research and develop building materials containing organic and inorganic wastes and waste-derived products.

The first phase covered an extensive literature search to identify, review and evaluate wastes with potential as matrices, reinforcements or fillers in building composites. Following limited laboratory studies, two matrices were selected for further study - an organic resin and an inorganic matrix developed by Material Systems Corporation. Seven reinforcement candidates and five fillers were chosen for detailed evaluation in Phase II.

The second phase concentrated on evaluating the structural and aesthetic properties of variously formulated composites containing a variety of solid waste materials.

Satisfactory products could be made using both inorganic and organic systems. Structural properties of several of the formulations were superior to existing commercial products. Fire-resistance properties were also often better than current fire-retardent materials. Economic analyses were performed on the more structurally promising products and several commercially viable materials appear possible.

The organic matrix containing rice hulls or peanut shells could be used as the basis for structural board, sheet rock panel replacement, a lumber substitute or fire doors. The inorganic matrix containing rice hulls as a filler/reinforcement could be used as the basis for a foam material with exceptional fire-withstanding properties. Possible products include fire-rated partition walls, a fire door core, and floor/ceiling panels.

This report was submitted in fulfillment of Contract No. 68-03-2460, Task 1, by Ekon Research Systems under the sponsorship of the U.S. Environmental Protection Agency. Research data for the report was summarized from a two-phase study conducted by Material Systems Corporation for Contract No. 68-03-2056 under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from November 1973 to September 1974, and work was completed as of September 1975.

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METRIC CONVERSION TABLE

The units in this report are those found in the two technical reports prepared by Material Systems Corporation. Engineering units as commonly used in this report reflect current practice in this country.

1 short ton	= 0.907 metric ton
1 long ton	= 1.016 metric tons
1 lb	= 0.454 kilos
1° F	= 5/9° C
1 Btu	= 252 cals
1 mile	= 1609 meters
1 inch	= 2.54 cm

[illegible]

Rinn Research Systems gratefully acknowledges the assistance of our Project Officer, Mr. Robert B. Lovbroth. This summary is written from a two-phase study done by Material Systems Corporation for the U.S. Environmental Protection Agency.

SECTION 1

INTRODUCTION

In recent years there has been an increasing focus on the development of marketable products derived from waste materials in order to defray the escalating costs of treatment and disposal. Various products obtained from waste materials have received attention, including chemicals, food or feed materials and energy. This report focuses on an on-going study to determine the feasibility of utilizing solid wastes for building materials.

Material Systems Corporation (MSC) together with the Solid and Hazardous Waste Research Laboratory (SHWRL), Environmental Protection Agency, has completed two phases of a suggested four phase study to evalute the technological and commercial possibilities of waste - derived composites. The first phase involved a joint and comprehensive literature search to identify wastes with potential as building materials. Limited laboratory studies were conducted on composite materials produced from the more promising wastes investigated.

A composite material was defined as a product containing a filler, a reinforcement and a matrix. A filler is a small fiber, flake or particle whose purpose is to displace the matrix from areas other than the reinforcement matrix interface and to assist in reinforcement. The reinforcement is a fiber, particle or a sheet whose primary purpose is to transfer load through the composite. Integration of the three elements of the composite material is accomplished by chemical adhesion by the matrix (binder) to the surfaces of the reinforcement and the filler.

Various characteristics were considered desirable for the filler, the reinforcement and the matrix. The wastes identified through the literature search were evaluated against these desirable properties. A listing of the evaluative criteria and the rating system used is found in Appendix A.

Filler materials reviewed included fly ash, crushed glass, phosphate slimes, silicate waste, shredded refuse, waste plastic, wood bark, rice hulls, taconite, red mud, coal waste foundry ash and sawdust.

Reinforcement materials reviewed included carbonized lignin, bagasse, wheat straw, bark, kenaf, bamboo, wood chips, cotton waste and glass roving. Sewage sludge, sawdust, rice hulls, plastic scrap and waste glass also received attention as reinforcements.

Matrix candidates derived from organic wastes of the agricultural and lumber industries included rice hulls, peanut shells, wood chips, etc. Matrices based on furfural phenol, dialdehyde starch/protein and cellulose received attention. The furfural phenol compositions were studied in depth during Phase II. MBC also investigated the use of an inorganic matrix proprietary to the firm containing magnesium oxychloride which could be derived from sea water.

As a result of Phase I research, it was determined that only two elements of the composite material could be reinforcements. Filler material, except for fly ash, could serve a dual role as reinforcement/filler. Thus, the study was directed towards the evaluation of the matrix and reinforcement materials only. During Phase II, various formulations of composite containing waste materials were evaluated for their structural properties, durability and workability.

Phase II also involved a study of possible products that could be derived from either the organic or inorganic matrix, and which contained wastes as either matrix or reinforcement (or both). Several limited economic analyses were performed to ascertain the commercial viability of any potential product made.

Though a number of non-waste materials were also evaluated, the thrust of the study was to utilize solid wastes. Through similar co-operative endeavors between government agencies and private industry, it will be possible to solve the mounting problems of solid waste management with ingenuity, environmental integrity, and commercial sensibility.

SECTION 7

CONCLUSIONS

Acid hydrolysis of waste materials containing pentoses (e.g. rice hulls, corn cobs, oat hulls, etc.) results in formation of furfural. On addition of phenolic wastes (wood wastes, wood pulp, etc.), a furfural/phenol resin is produced in situ. Alternatively, acid treatment of wheat straw, rice hulls, and corn cobs yields a binder with structural integrity on molding.

Several formulations with superior properties can be made through acid hydrolysis of cellulose/pentose containing wastes with or without addition of additional binder. Possible products to be developed from various organic wastes (especially rice hulls) include:

structural board
replacement sheet rock
lumber substitute
fire doors.

Because of the high silica content of rice hulls, they impart a high degree of fire resistance to composites.

The MBC proprietary binder containing magnesium oxychloride waste was most successful in an organic matrix with rice hulls as filler/reinforcement and inorganic fillers. By varying composition, it was possible to produce a high density structural composite termed a laminate, and a low density core composite similar to a foam.

The laminates evaluated demonstrated highly desirable structural properties, low cost and excellent fire-retardent properties. Possible products based on inorganic matrix compositions include wood substitutes, fire rated partition walls, fire door core panels and floor/ceiling panels.

Although waste materials from many sources were evaluated for effectiveness as filler/reinforcement/matrix, only a few of the materials tested showed much promise. In addition to the rice hulls, corn cobs, wood wastes and wheat straw mentioned above, fly ash displayed some potential as a filler with both the organic and inorganic matrices. Though costing as much as the currently used calcium carbonate filler, the use of fly-ash as a filler has value as a waste disposal technique.

SECTION 5

RECOMMENDATIONS

As several of the formulations evaluated showed commercial promise, it is recommended that product development continue for those formulations showing structural superiority and commercial viability. This development should include testing and evaluation to a sufficiently high level to assure qualification for specific products under existing building standards and codes.

The insulating "foams" prepared from the MDC binder, rice hulls and inorganic fillers should receive further attention. Procedures for manufacture should be investigated, as well as possible marketing strategies for products made from the inorganic matrix.

Structural boards based on a furfural-phenol resin, (produced from rice hulls in particular) should continue in development. A similar formulation shows potential as a sheet rock substitute and a fire door core. These three potential products derived from organic wastes (rice hulls, peanut shells, wood wastes, etc.) should be further developed.

Therefore, in order to completely explore the potential of waste materials, it is proposed that two more phases should be funded:

(a) A Phase III study to develop and qualify the products mentioned above for both organic and inorganic materials; and to construct a transportable demonstrator 8' x 12' module of the test materials.

(b) A Phase IV study to evaluate the effect of weathering and aging on the module and other qualified products of Phase III.

SECTION 4

EVALUATION OF MATERIALS

FILLER

The main purposes of a filler are to improve the properties and to reduce the use of more expensive materials in the making of a matrix composite. Calcium carbonate and alumina have been used as fillers in the past. This study evaluated the possibility of utilising wastes from the paper and wood industries as well as municipal, industrial and mining wastes.

Fly ash, waste plastic, wood bark and rice hulls were chosen as primary candidates for fillers. Crushed glass, shredded refuse, taconite, red mud, phosphate slimes, silicate waste, coal foundry ash and saw dust were evaluated also. Fly ash was the main candidate considered because of its universal availability, and because previous test on fly ash have indicated its potential as a filler.

Filler candidates were evaluated against the following criteria:

(a) destructive reactivity and rate of reaction;
(b) temperature of decomposition (at least 750°F or 399°C);
(c) "grindability" and fineness of mesh;
(d) density;
(e) absence of aroma;
(f) performance with various matrix and reinforcement materials;
(g) availability.

The rating system may be found in Appendix A. Table 1 shows the ratings of the fillers tested. These ratings are based on an examination of the literature. References may be found in the appropriate section at the back of this report. Table 2 summarises the source and availability of these possible fillers.

Initially, fly ash was employed as a filler for polyester fiberglass reinforced composities replacing the usual calcium carbonate filler. After 1500 hours of continuous exposure in an accelerated weathering test, the mechanical and physical properties of the test filler were evaluated. The fly ash filler exhibited properties equivalent to the calcium carbonate.

While the fly ash retained its appearance, a color problem could arise as fly ash wastes range in color from dark grey to near black depending on their source.

TABLE 1

EVALUATION OF FILLERS

FILLER							
Ash	5	5	5	3	5	8	31
Crushed glass	5	4	5	3	5	5	27
Phosphate slimes	3	4	5	4	3	2	20
Silicate waste	5	4	5	3	2	2	21
Shredded refuse	2	3	3	4	2	7	21
Waste plastic	3	1	5	4	5	1	19
Wood bark	4	1	4	4	2	8	23
Rice hulls	5	3	3	1	5	6	27
Taconite	4	3	5	3	5	3	23
Red mud (alum. ore)	4	3	5	3	2	2	19
Coal waste (recover alumina)	5	5	5	3	5	2	25
Foundry ash	5	5	5	3	5	2	25
Saw dust	3	2	1	5	5	4	24

TABLE 2 [illegible]

[illegible]	[illegible]	[illegible]
Ash	Burning of coal, generated by [illegible] incinerators, wood refining, etc.	Fly ash is readily produced throughout U.S. with exception of N. Calif., Or and Ia. Fly ash is fine, inert and performs well in composite, will not support combustion -- [illegible]
Crushed glass	Industrial & [illegible]	Has possible recycle value. Primary supply is industrial. Has weld have to crush. Does not support combustion -- [illegible]
Phosphate slimes	Phosphate mining in Florida (only)	Some studies have used it in brick production. Slime has high moisture content and must be dried. Because of drying costs probably not economical.
Silicone waste	Paper processing	Local sources
Shredded rubber	Municipalities	Supply limited due to lack of municipal sorting and shredding facilities. May react with aerosol, doesn't age well, variety of shapes causes problems.
Waste plastic	[illegible] and industrial waste	Smaller particle sized material used for filler, larger sheets for scrap. Flammability is a concern; mechanical, surfaces and material waste compatibility should be studied.
Wood bark	Lumber industry	Fine material for filler. Flammability a problem. Widely available but density differences with waste could be a problem.

TABLE 2 (continued)

Candidate Indicator	Source	Note
Rare halls	Rare harvesting	May have to be crushed. High silicon content characterized as a filler, widely available in parts of earth. May be flammable or heated by environmental factors.
Bentonite	Iron ore processing	Localized availability, low inert and env. cohesion.
Red mud	Aluminum processing	Localized in Texas, Ark., Ala., and La., mainly waste from bauxite or phosphate lines. Byproducts: concrete and brick made from it. Fire, inert and env. cohesion.
Soil waste	Potential to produce alumina	Alumina filler used by MIT for 6 years - experimental.
Foundry ash	Arc furnaces, coal combustors	Sporadically used as a filler in epoxy resins. Local supply (similar to fly ash).
Slag dust	Cement industry	Flammability a problem. Density incompatibility with matrix a problem.

It was noted that fly ash exhibited thixotropic behavior in the polyester resin. This resulted in a condition of decreased viscosity or increased flow with application of pressure or force. Therefore, the concentration was limited to 75 parts fly ash per 100 parts resin (c.f. calcium carbonate concentration of 100 parts per 100 parts resin).

Though the optimum concentration of fly ash in the polyester matrix was lower than the calcium carbonate in the same matrix, fly ash could be used in equivalent amounts to calcium carbonate in MBC's inorganic matrix. The overall performance of fly ash as a filler with either matrix was very promising. Fly ash obtained the highest rating of all the fillers evaluated, see Table 1. Calcium carbonate and fly ash cost about the same. Therefore, use of fly ash as a filler is cost-effective only in that this use effectively disposes of a waste material.

The ineffective fillers were sawdust, paper pulp, waste paper and computer cards. They were tested with conventional organic systems, the waste organic system and the MBC inorganic matrix.

As the Phase I study showed that filler material (except fly ash) could serve a dual role as reinforcement, filler materials were not separately evaluated in Phase II but were included as part of the reinforcement evaluation (q.v.).

REINFORCEMENT CANDIDATES

The reinforcing system can serve a variety of purposes:

(a) in an organic matrix it can both reinforce and/or supply the resin;
(b) in an inorganic matrix it can both reinforce the matrix and/or create voids in the matrix (syntactic foam).

During Phase I of this study, various wood, agricultural, industrial and municipal wastes were evaluated as reinforcement candidates. Kenaf, bamboo and glass roving which are not wastes were also evaluated. Reinforcement candidates can be fibers, sheets or particles. Table 1 identifies the materials evaluated in source, category and availability. The materials were evaluated for the following properties:

(a) tensile strength and modulus;
(b) surface to volume ratio;
(c) length to width ratio;
(d) absence of aroma;
(e) availability;
(f) compatability with matrix.

The rating system may be found in Appendix A. Table 4 summarizes ratings for each of the reinforcement candidates evaluated. These ratings are based on the literature search. References are collected at the back of this report.

TABLE 1

REINFORCEMENT MATERIALS CONSIDERED

Material	Category	Source	Availability and Notes
Carbonized lignin	Fiber	Graphite fibers	Preliminary research stage, not considered
Bagasse	"	Pulp from processed cane sugar	Limited supply in U. S. highly localized. Supports combustion.
Wheat straw (cereal straw)	"	Cereal harvest	Stiff wax layer causes bond difficulty, combustible.
Bark	"	Lumber industry	Inner materials can be used, short fibers. Commercially developed.
Kenaf	"	Cordage crop (jute substitute)	Central America, S.E. Asia. World wide shortage, combustible, insect prone.
Bamboo	"	Bamboo harvest	Difficult to fiberize, supports combustion, insect prone. U.S. limited.
Wood chips	"	Lumber industry	Difficult to fiberize, supports combustion. Affected by insects, fungus, limited supply.
Cotton wastes	"	After gin process (hulls, leaves, stems, seeds)	S.E. U.S., marginal properties, affected by fire, insects, fungus. Good supply.

TABLE 3 (continued)

Material	Category	Source	Availability and Notes
Glass roving	"	Not a waste commercial material	Good reinforcement at economic values. An inorganic resists fire, insects, fungi.
Paper	Sheet	Paperwaste	Many uses, limited supply. Affected by fire and environmental factors.
Sewage sludge	Particle	Municipal sanitation sources	Low reinforcing qualities experimental bricks made. Not economical except for waste removal.
Sawdust	Particle	Lumber industry	Full to low strength particle board, large surface area requires high matrix content, already well used.
Rice hulls	"	Rice harvest	Ash has 95% silica content permitting high fire protection, supply in California, Gulf Coast Bricks made.
Plastic scrap	"	MSW and industrial waste	Size and shape cause problems. Primary supply is industrial. Speciality application.
Waste glass	"	MSW and industrial waste	Crushed, similar shape problems to plastic. Experimentally reinforces bricks and concrete, recyclable to new glass.

TABLE 4

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Carbonized lignin	5	5	5	5	3	0	23
Paper	5	4	5	5	5	4	28
Sewage sludge	3	3	3	3	1	7	17
Sawdust	1	4	1	1	5	10	22
Bagasse	4	3	3	3	3	0	21
Wheat straw	4	3	5	5	3	6	25
Rice hulls	3	4	3	4	5	6	25
Bark	4	4	3	4	5	0	20
Plastic scrap	4	3	5	5	5	6	28
Kenaf	4	3	5	5	3	4	13
Bamboo	3	5	3	4	5	3	21
Wood chips	4	1	1	2	3	0	20
Waste glass	4	5	1	1	5	6	22
Cotton waste	4	4	3	4	5	3	27
Glass roving	5	5	5	5	5	5	10

Before final selection of materials for further study in Phase II, the possible uses of the composite bricks were examined in relation to properties exhibited by bricks made with specific fillers. The bricks could be used as (1) primary structural materials; (2) bearing and framing materials; (3) secondary structural materials; (4) floor surface materials.

Primary Structural Materials - These are materials that are used for transferring primary loads such as tension, compression and shear. Typical applications would be a load bearing wall surface, wall structural core such as a corrugation, roof surfaces, etc. Typical axial stress levels would range from 1,000 to 10,000 psi depending on design. Fiber reinforcements are the primary candidates. Glass roving, although not a waste, is inexpensive, available and can be used with any of the matrix sections. Paper is also an acceptable reinforcement but is currently less available than glass roving. Kenaf, sisal, jute and similar fibers also perform well but are in short supply. The candidates chosen for Phase II based on all the above criteria were glass roving and waste paper.

Bearing and Framing Materials - These materials are used to transfer joint loads and close out openings. Typical applications are sill plates, window and door frames, roof and floor beams. Typical axial and bearing stress levels would range from 100 to 3000 psi depending on design. For this use of brick, the candidates chosen for further study in Phase II were rice hulls, bark, plastic scrap, wood chips and cotton waste.

Secondary Structural Materials - These are materials used for non-load bearing wall and ceiling panels. Typical axial stress levels would range from 100 to 1000 psi depending on the design. The candidates selected for further study in this category were rice hulls, bark, wood chips and waste paper.

Floor Surface Materials - These materials are subjected to bearing and abrasion. The reinforcing candidates selected were waste paper, rice hulls, bark and wood chips.

Phase II - Screening Processes

The materials chosen from Phase I were initially screened to determine the "acceptability" and "feasibility" of products produced from the materials using both an organic and an inorganic matrix. "Acceptability" was defined as the production of a material with properties achieving commercial standards. "Feasibility" of use indicated that it was possible to produce a composite brick with a particular reinforcement candidate and either the organic or inorganic matrix. Table 6 summarizes this data. After this initial screening, the costs of the materials were determined F. O. B. Source (see Table 5).

Transportation costs are a function of material density -- the lighter the material, the higher the per pound cost. Therefore, it would be desirable to densify the lighter materials by compacting or baling where practical.

TABLE 5

TYPICAL COSTS OF REINFORCEMENT F. O. B. DUKE

Reinforcement	$Cost/lb
Corn cobs	0.0075*
Straw	0.0020 - .010†
Rice hulls	0.0020 - .0025
Cotton waste	0.0020 - .010
Peanut shells	0.0075§
Wood bark	0.01
Saw dust	0.01
Pine shavings	0.01
Alder shavings	0.01
Douglas fir shavings	0.01
Redwood shavings	0.01
Ash shaving	0.01
Plastic scrap	Unable to establish a cost
Reject styrofoam beads	0.25
Glass fibers	0.43
Silvacon 412	0.0465

* Cornnuts, Inc. - Oakland, California
† The cost would vary with demand. It will not be less than rice hulls or more than wood shavings.
§ Gold Bluff Peat Mill Company
This is a nominal cost paid by shipboard manufacturer. The cost may vary 10% with supply and demand.

A 500 mile transportation radius was selected as this would provide a factory with 785,400 square miles of producing waste sources. This area was considered more than adequate to supply necessary reinforcement material. Table 7 shows the transportation costs per pound for several reinforcement candidates gathered within this 500 mile radius.

The reinforcement candidates were rated according to product potential. Figure 1 illustrates the ratings for reinforcements used with inorganic matrices and Figure 2 shows the ratings with organic matrices. The ratings were based on eight criteria listed in each figure and graded from 0 to 4. While a score of 32 represented the maximum points obtainable, the value of 20 points was established as the "preferred" level of selection. A rating of 16 was considered "acceptable" and represented "average reasonable" potential. For an individual criterion, a rating of 2 points represented "reasonable" potential. Mail retention was used as a criterion for applicability to conventional construction; the other criteria represented requirements for a feasible product.

TABLE 6

SUMMARY OF REINFORCEMENTS, PHASE II

Reinforcement	Used With Organic Matrix		Used With Inorganic Matrix	
	Feasible	Acceptable	Feasible	Acceptable
Agricultural Waste				
Corn cobs	X	X		
Straw	X	X		
Rice hulls	X	X	X	
Cotton waste	X	X	X	X
Peanut shells	X	X	X	X
Industrial Waste				
Wood bark	X	X	X	X
Saw dust	X	X		
Pine shavings	X	X		
Alder shavings	X	X		
Douglas fir shavings	X	X		
Redwood shavings	X	X		
Ash shavings	X	X		
Plastic scrap			X	X
Reject styrofoam beads			X	X
Reject graphite fibers			X	X
Sisal scrap			X	X
Fly ash			X	X
Commercial Waste				
Waste paper	X	X		
Paper pulp			X	X
Computer cards			X	X
Non-Waste				
Glass fibers			X	X
Nivacon 412	X	X	X	X

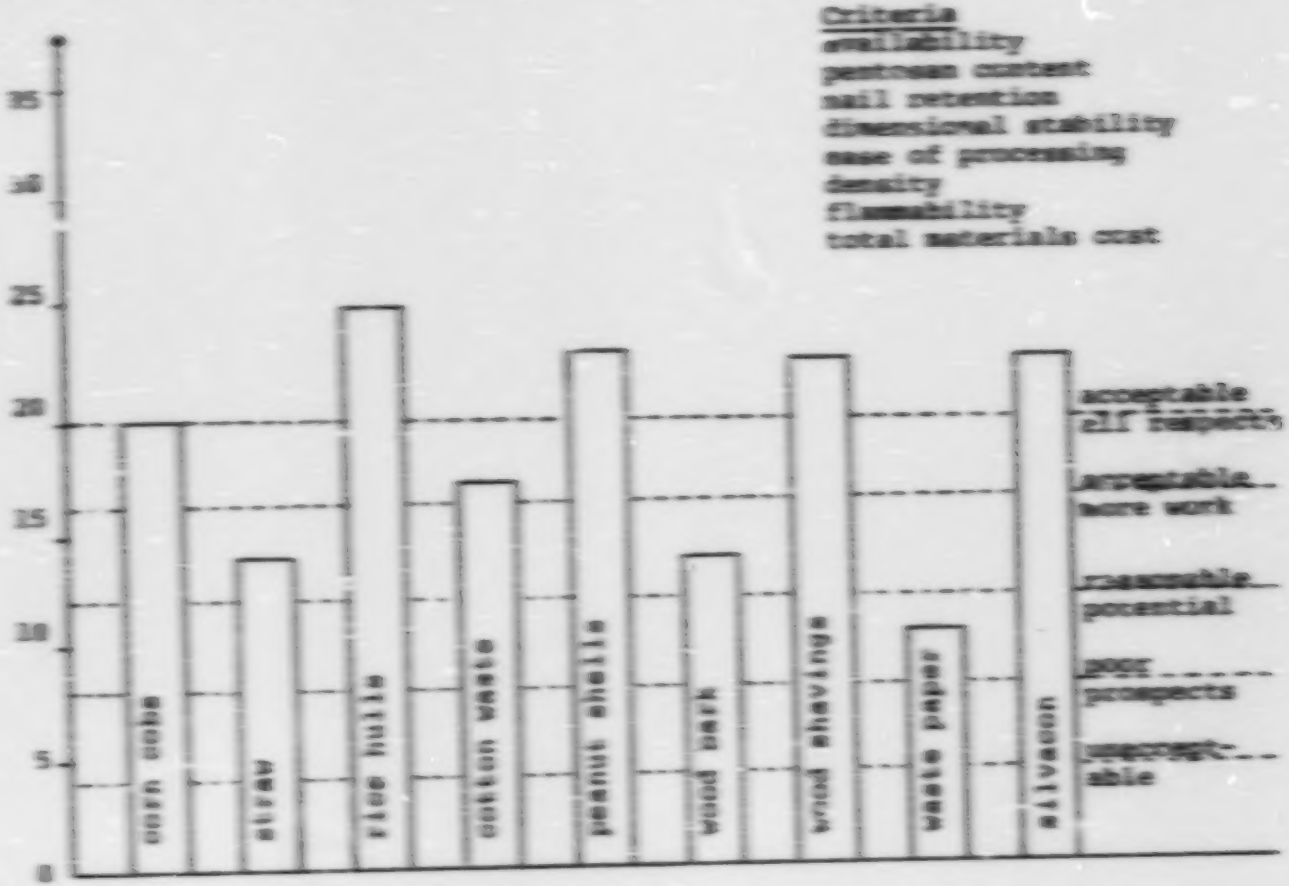
TABLE 7

REINFORCEMENT TRANSPORTATION COSTS FOR 500 MILES

Reinforcement	$/ton/lb
Corn cobs	0.0062 - 0.0125
Rice hulls	0.014
Peanut shells	0.013
Wood shavings	0.010

steel scrap
rice hulls (primary)
rice hulls (magnesium oxychlo)
cotton waste
plastic scrap
reject styrofoam beads
fly ash
wood bark
paper pulp
scrap tires
steel scrap
sawdust
reject graphite
glass roving
Ratings

Figure 2 Ratings of Reinforcements Used with Organic Matrices



Organic Binders/ Waste Products Composites
(Screening Phase)

After thorough evaluation and review, it was concluded that rice hulls, peanut shells, corncobs, woodshavings and silvacon would be the best candidates as reinforcements with an organic matrix. Cotton waste should only be considered a possible reinforcement material if the disposal problems are sufficient to counter poor characteristics displayed (see Matrix Section). Straw must be pretreated to destroy or break up its resistant surface before it can be used as a reinforcer. Waste paper cannot generate furfural and therefore by itself was not effective. Even when used in combination with other materials, it showed little promise.

Rice hulls are the best reinforcement for an inorganic matrix. Plastic scrap and reject styrofoam beads show definite promise but are limited in supply. In the distant future, sorting of MSW could supply a quantity of plastic scrap. Fly ash, sisal scrap and silvacon are of lesser interest and all other candidates should be disregarded.

TABLE 8

SOURCE AND AVAILABILITY OF FINAL REINFORCEMENT CANDIDATES

Reinforcement	Quantity	Source
Corn cobs	1,500 - 2,000 tons/yr	Cornnuts Inc., Oakland, Calif.
"	Similar	Beef milk in Calif. and Midwest
Rice hulls	3,000 tons/month	Comet Rice Mills, Houston, Texas
"	+150 tons/month	C.E. Grosjean Rice Milling Co., San Francisco, Calif.
"	25,000 - 30,000 tons/yr	Bluffiet Bros., Gridley, Calif.
"	Similar	Louisiana and Texas
Cotton waste	Unknown	Unknown
Peanut shells	150,000tons/yr	Texas, Louisiana, Georgia, Alabama, Arkansas, Mississippi, Florida
"	3,000 tons/month	Gold Dist Feed Mill, Comanche, Texas
Wood shavings	Unlimited	Northwest, South and Southeast
Silvacon	Unlimited	Weyerhauser
Plastic scrap	Unlimited	Unknown
Reject styrofoam beads	Limited	Unknown
Fly ash	30 x 10^6 tons/yr	Coal-fired furnaces

MATRICES

The matrix is the binder which integrates the filler and the reinforcement and causes the composite to perform as a single material. This is accomplished by chemical adhesion of the matrix to the surface of the reinforcement and the filler.

A number of both organic and inorganic matrices were considered; the organic matrices to offer versatility in processing, and the inorganic to provide a high degree of non-flammability to the final product.

In the Phase I evaluation, candidates included dialdehyde/protein starches, furfurals, cellulose, phenols and inorganics (cements). These materials were rated on:

(a) curability temperature;
(b) absence of aroma;
(c) processability (time required, pressure and temperature);
(d) physical state;
(e) toxicity;
(f) decomposability;
(g) color;
(h) availability.

A detailed explanation of the meanings assigned to these terms and the rating system employed is found in Appendix A. Table 9 summarizes the ratings and gives the final scoring for the matrices initially considered. References to the literature on which these ratings are based are found at the back of this report.

It was concluded that furfurals, phenols and inorganics should be further studied in Phase II.

1. Organic Matrix

Some of the most versatile and strong resins commercially available are based on the condensation polymerisation of a phenol with an aldehyde. Though formaldehyde is normally used, it is possible to replace this chemical with other aldehydes. In practice this is rarely done because of expense and technological difficulties in processing. Furfural and furfuryl alcohol based resins are in use and have been utilised as molding compounds and matrices for reinforced composites. Furfuryl alcohol is made by hydrolysis and dehydration of pentosan in rice hulls, corn cobs, oat hulls, manures, etc. to produce furfural which is then hydrogenated. However, furfural is itself highly reactive and known to condense with phenols to give resinous products.

It would be very useful to obtain a construction material based on furfural-phenol resins obtained from waste materials without the cost-increasing step of isolating the reactants. The in situ reaction of the furfural generated would also eliminate the cost of catalytic hydrogenation

TABLE 9

MATRICES CONSIDERED, PHASE I MATRICES

Matrix	Processability										
Dialdehyde/protein starches	5	5	1	1	5	1	5	1	1	8	33
Furfurals (manure)	5	4	5	5	5	5	5	5	0	6	45
Furfurals (rice hulls, bagasse)	5	4	5	5	5	5	5	5	0	8	47
Inorganics (cement)	5	5	1	5	5	1	5	5	2	10	46
Cellulose (reactants)	3	4	5	3	3	4	5	1	2	6	35
Phenols	3	4	5	1	3	5	5	5	1	6	38
Lignin	3	4	5	3	3	5	5	3	1	7	39

to furfural alcohol and the need to add presynthesized aldehyde to the phenol containing wood waste.

The process was initially visualized as permitting the furfural to remain in solution and then adding phenol containing wood waste material or lignane from wood pulp waste to form furfural-phenol resins. It was thought that by finely dividing the rice hulls, corn cobs or other sources of pentose prior to reaction, that it would be possible to allow these fibrals to remain in the material to act as additional fillers. If this did not prove feasible, then the resin would be isolated, and the material formed and heated to finish the condensation.

Three approaches to the use of a furfural-phenol matrix received attention in Phase II:

(1) development of a matrix using a commercial furfural alcohol source

with waste materials chosen for reinforcement and filler candidates;

(2) a three step in situ formation of furfural with addition of organic resins or resin precursors;

(3) a simpler two-stage process for in situ formulation of furfuryl from waste without added organic resins or resin precursors.

These three approaches are analysed below:

(1) Development of a matrix using using a commercial furfural source

Referring to the chemistry outlined in Appendix B, the formulation of the resin was tested using the Quaker Oats "Quacor" furfuryl alcohol-based resin. This gave the opportunity of testing a resulting matrix material theoretically similar to the expected in situ resin produced by either the two or three stage process.

A series of commercial formulations were prepared. Two experimental runs were conducted on the MRC continuous process machinery. The first run used resin mixes twice as viscous as that of the production polyester mix. Line speed was 3 feet per minute and production speed was between 5 and 10 feet per minute. Three ovens were used at temperatures of 77°C, 82°C, and 99°C respectively. None of the formulations was fully cured after treatment in oven #3. After overnight air cure and post curing at 127°C and 141°C for ten minutes at each temperature, A and B were fully cured. Table 10 shows the results of evaluated variations in fillers and catalyst. Oven #1 was set at 71°C; oven #2 at 102°C and oven #3 at 177°C. All samples appeared well cured after oven #3 though some samples were post cured at 177° for two hours. The results of mechanical and flame spread test are shown in Table 11.

It was concluded that furfural is processable on the production system and will develop a product equivalent to or superior to the presently qualified product. The studies indicated no insurmountable difficulty in processing composites based on matrix resins using the furone ring system.

To prepare an aesthetic surface for use as exterior wall panels, it was found most effective to add crushed rock, glass, plastic, etc. to the composite on the belt, and then cure the entire system.

| | | |

TABLE 12

FORMULATIONS FOR RUN 11

Form.	Resin		Solvent		Filler		Catalyst	
D	Quaker HP100A	(100)	Furfuryl Alcohol	(5)	Huber 35	(60)	HP104B	(3)
E	"	(100)	"	(5)	"	(80)	"	(3)
F	"	(100)	"	(5)	"	(100)	"	(3)
G	Quaker RX300		"	(5)	"	(60)	"	(3)
H	Quaker HX100A		"	(5)	C-31*	(60)	"	(3)
I	"	(100)	"	(5)	"	(60)	"	(4)
J	"	(100)	"	(5)	Huber 35	(60)	"	(4)
K	"	(100)	"	(5)	"	(60)	"	(4)

*C-31 is alumina hydrate

TABLE 13

EVALUATION OF RUN 11 - FORMULATIONS D-K

Form.	Flame Spread		Tensile	
	Air Cured	Post Cured	Air Cured	Post Cured
D	37	16	6850	8015
E	20	13	5480	6020
F	20	25	3680	4050
G	16	18	7380	6310
H	31	18	5080	4890
I	33	18	4175	4780
J	33	27	3490	3560
K	22	18	7630	7600
Commercial Building Material	100		2000-5000	

(3) Three stage process of in situ formation with additives

As indicated in Appendix B, furfural can be derived from rice hulls or corn cobs by acid hydrolysis under pressure. The purpose of this study was to:

(a) determine if pressure was really necessary;
(b) determine yield of furfural at lower pressures.

The additives were used to interact with the furfural, and/or stimulate furfural formation, and/or reinforce and absorb excess furfural.

It was theorized that a novolak resin would be formed in situ by refluxing rice hulls (source of furfural) with wood bark (source of phenol) at atmospheric pressure. Addition of a furfural or hexamethylene tetramine "seed" would produce further cross linking.

After preparation, rice hulls were refluxed with dilute hydrochloric acid followed by addition of phenol and further refluxing. The mix was air dried, hexamethylene tetramine was added and the resulting material molded at 150°C and 250 psi. There was no flow, the molding was resin starved and easily breakable. A second series of experiments was carried out refluxing the rice hulls in dilute hydrochloric with phenol present initially.

Molding trials were carried out on the hydrolysis mixtures after addition of Silvacon 412 as a filler and 10% dry weight of chopped glass fibers as reinforcement.

Tests performed on the hydrolysis mixture did not determine the exact yield of furfural. However, it was concluded that with a roughly 3-6% HCl solution and refluxing at 100° for 15-20 hours, it was possible to produce enough furfural to give a moldable material. A lower acid concentration (1%) and shorter reflux time (3-5 hours) did not produce a moldable product.

Successful resins were also obtained by refluxing rice hulls or corn cobs without bark or other phenolic materials present. After hydrolysis, Silvacon 412 was added to absorb excess furfural and act as a filler. Addition of shredded newspaper reinforced the composite which was cured for 20 minutes at 150°C and 500 psi.

The effect of different concentrations of wood bark on the hydrolysis mixture was also investigated. Addition of hexamethylene tetramine improved the integrity of the moldings. Table 14 gives various formulations for the hydrolysis mixture and Table 15 given formulations for various molding mixtures.

TABLE 14

COMPOSITION OF HYDROLYSIS/CONDENSATION MIXTURES

Mixture Number	Corn cobs (g)	Rice hulls (g)	Wood bark (g)	HCl (ml)	Water (ml)	Silvacon[a] 412 (g)
30	120	-	-	12	200	50
26	120	-	60	12	200	70
31	120	-	90	12	200	70
25	120	-	120	12	220	60
29	-	30	-	3	115	40
28	-	30	15	3	115	30
24	-	30	22.5	3	115	36
27	-	30	30	3	115	30

[a]Added after completion of hydrolysis

TABLE 15

FORMULATION OF RESIN MIXTURES

Sample	Wet Mixture[a] (g)	Furfural (ml)	Furfuryl Alcohol (ml)	Novalac (g)
A	35	-	-	-
B	35	-	-	3
C	35	1	-	3
	Above for mixtures 29, 30.			
A	24	-	-	-
B	-	-	-	2
C	24	1	-	2
D	24	-	1	2
E	24	-	2	2

Above for mixtures 31, 26, 25, 28, 27, 24

[a]Wet mixture is the hydrolysis mixture plus Silvacon.

The above mixtures produced cross-linked resins, insoluble in water, and retaining much of their strength after 24 hours water immersion. An attempt to produce moldings by adding alkali after initial acid hydrolysis was not successful, producing water-soluble resins.

The yield of furfural was investigated under various reaction conditions including reaction time, charge of acid and mechanical agitation. The amount of furfural was determined by titrametric analysis using sodium bisulfite.

The yields of furfural were studied after 3, 10 and 20 hours. It is not certain that the reaction came to equilibrium kinetically. After 20 hours, rice hulls gave a yield of 4.13% furfural and corn cobs yields of from 1.26% to 10.9%. Mechanical mixing did not improve yield of furfural. Replacing hydrochloric acid with sulfuric acid did not alter the yield of furfural produced from rice hulls. The yield from acid hydrolysis of corn cobs was 50% lower with the sulfuric acid.

All compositions discussed were molded, dried and tested (see Table 16). It was found that:

(1) Modulus of rupture increased with density for mixtures containing no wood bark, and a high proportion of wood bark, rice hulls/wood bark, and corn cobs/wood bark;

(2) Addition of newspaper did not seem to improve modulus of rupture and in some cases even lowered density and strength;

(3) Addition of furfural (samples designated C) or addition of furfuryl alcohol (samples designated D, E) did not improve the strength.

It was concluded that future work should concentrate on the processing of materials without the use of external binders.

TABLE 16

[illegible] COMPOSITION

Sample	Width (in.)	Thickness (in.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (psi)
30A (1)	0.994	0.180	19.3	1.09	8.0	1490
30A (2)	0.985	0.163	17.1	1.07	5.0	1146
30B (1)	0.985	0.212	25.3	1.12	9.0	1219

TABLE 16 (continued)

Sample	Width (in.)	Thickness (in.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (psi)
30B (2)	0.994	0.208	23.1	1.13	7.8	1084
30C (1)	0.985	0.190	19.7	1.04	8.4	1417
30C (2)	0.993	0.193	19.5	1.03	8.2	1330
26A (1)	0.996	0.254	24.7	0.99	6.4	781
26A (2)	1.000	0.255	24.8	0.99	6.4	775
26B (1)	1.000	0.280	27.5	0.96	10.7	763
26B (2)	0.994	0.285	27.3	0.97	10.7	790
26C (1)	0.999	0.255	25.7	1.02	12.5	1154
26C (2)	0.995	0.253	24.8	1.00	10.6	1001
26D (1)	0.999	0.282	27.5	0.99	15.5	1171
26D (2)	0.993	0.280	27.5	1.00	16.7	1291
26E (1)	0.998	0.310	29.4	0.96	18.9	1180
26E (2)	0.994	0.312	29.7	0.94	16.4	1010
23A (1)	0.995	0.228	25.2	1.12	14.0	1624
23A (2)	0.998	0.233	25.2	1.10	11.4	1258
23B (1)	1.000	0.235	24.9	1.08	10.7	1168
23B (2)	1.002	0.240	24.5	1.04	10.1	1052
23C (1)	1.003	0.237	25.2	1.08	10.6	1131
23C (2)	1.004	0.239	25.0	1.06	12.0	1255
23D (1)	1.000	0.284	28.6	1.02	18.2	1357
23D (2)	0.996	0.279	28.6	1.03	17.4	1344
23E (1)	0.996	0.286	29.2	1.04	18.4	1353
23E (2)	1.000	0.290	29.1	1.02	23.7	1694
25A (1)	0.997	0.299	27.2	0.92	8.0	538

TABLE 16 (continued)

Sample	Width (in.)	Thickness (in.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (psi)
25A (2)	1.000	0.296	27.2	0.93	7.4	505
25B (1)	0.998	0.306	28.9	0.96	9.9	634
25B (2)	1.004	0.310	28.9	0.95	8.7	544
25C (1)	0.999	0.298	28.2	0.96	9.7	659
25C (2)	1.000	0.299	27.9	0.95	11.6	780
25D (1)	0.998	0.321	29.9	0.95	12.4	733
25D (2)	1.000	0.322	29.9	0.92	13.0	762
25E (1)	1.000	0.370	31.7	0.87	12.6	553
25E (2)	0.998	0.370	32.6	0.89	13.4	587

TABLE 17

RICE HULL BASED COMPOSITION

Sample	Width (in.)	Thickness (in.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (psi)
A (1)	0.985	0.207	23.5	1.15	13.5	1918
A (2)	0.985	0.207	22.9	1.12	12.5	1776
B (1)	0.997	0.323	21.6	0.99	16.5	951
B (2)	1.002	0.318	20.7	0.98	13.1	744
C (1)	1.000	0.210	22.1	1.07	7.1	969
C (2)	1.004	0.214	23.9	1.09	9.7	1273
A (1)	0.985	0.222	21.5	0.98	7.5	913
A (2)	0.985	0.218	20.8	0.97	5.5	694
B (1)	1.000	0.350	34.9	1.01	20.0	980
B (2)	1.000	0.346	34.4	1.01	26.0	1303
C (1)	1.005	0.302	33.7	1.13	23.51	1538

TABLE 17 (continued)

Sample	Width (in.)	Thickness (in.)	Weight (g)	Density	Flexural Load (lbs)	Modulus of Rupture (psi)
C (2)	0.996	0.290	30.7	1.08	21.91	1540
D (1)	1.004	0.315	30.3	0.98	14.01	846
D (2)	1.000	0.315	29.1	0.94	12.75	770
E (1)	1.005	0.372	33.6	0.91	15.1	652
E (2)	1.000	0.370	33.6	0.92	17.0	745
A (1)	0.995	0.280	27.2	1.06	16.1	1438
A (2)	1.000	0.280	27.2	0.99	13.2	1014
B (1)	1.000	0.330	34.1	1.05	17.5	984
B (2)	1.001	0.340	37.7	1.12	16.6	863
C (1)	1.001	0.322	32.5	1.03	14.7	853
C (2)	1.000	0.317	32.5	1.04	14.5	866
D (1)	1.002	0.317	30.8	0.99	14.7	879
D (2)	1.004	0.317	30.6	0.98	14.7	877
E (1)	1.007	0.373	33.5	0.91	12.4	530
E (2)	0.998	0.372	34.0	0.93	18.2	575
A (1)	1.003	0.298	29.1	0.99	9.5	640
A (2)	1.000	0.292	28.0	0.97	8.5	598
B (1)	1.002	0.321	31.4	0.99	13.0	755
B (2)	1.006	0.320	31.5	1.00	14.7	859
C (1)	1.001	0.356	34.4	0.98	10.5	496
C (2)	1.003	0.356	32.9	0.93	10.7	507
D (1)	0.999	0.373	33.3	1.04	23.6	1020
D (2)	1.002	0.377	37.8	1.03	23.0	969
E (1)	1.006	0.344	33.1	0.98	19.5	983

(3) Two step process of in situ formation of furfural from wastes without isolation.

It was discovered that after acid treatment cellulose containing materials (with pentosans) yield a binder during molding. Initial work was conducted on wheat straw, rice hulls and corn cobs. Acids used were 3% solutions of hydrochloric acid, phosphoric acid, oxalic acid, chromic acid, p-toluene sulfonic acid and hydrochloric acid with 1% aluminum chloride. The materials tested were soaked in acid solution for an arbitrary 30 minutes after which they were dried at room temperature or oven-dried at 50-60°C. The treated materials were molded for ½ minutes at 120-150°C and 500 psi.

The p-toluene sulfonic acid was most successful; oxalic acid and boric acid failed to catalyse binder formation; chromic acid and the hydrochloric acid + aluminum chloride mixture caused charring. The effect of shorter acid treatment periods is shown in Table 18.

TABLE 18

ASH AND RICE HULLS, ACID TREATED FOR SHORT PERIODS

Sample	Material	Acid Time (Min.)	Treatment Temp (°C)	Molding Time (Min.)	Molding Temp (°C)	Pressure (Psi)	Density	Modulus of Rupture (Psi)
YP-64	Ash + 3% H_3PO_4	1	24	3	140	300	0.79	1205
YP-64	Ash + 3% H_3PO_4	1	24	3	140	500	1.08	3023
YP-64	Ash + 3% H_3PO_4	1	80	3	140	300	0.78	993
YP-64	Ash + 3% H_3PO_4	1	80	3	140	500	1.10	2570
YP-46	Rice hulls + 3% p-toluene sulfonic acid	1	24	5	140	500	*	*
YP-46	Rice hulls + 5% p-toluene sulfonic acid	5	60	5	140	500	1.10	1308

* Dry, falls apart, no resin formed.

These experiments clearly demonstrate the feasibility of industrial processing. In any specific case, optimal treatment parameters should be investigated, depending on the types of wood and particle size distribution.

Cotton waste was successfully molded with hydrochloric acid, phosphoric acid and p-toluene sulfonic acid. The main source of binder seemed to be the dried stalks and flower pods. Wheat straw composites did not weather well containing a great deal of pith not removed by initial blending. Wood wastes gave excellent results on treatment with phosphoric acid giving moldable materials without need of an added binder. Wood wastes of particle size less than 4 mesh gave the best final products.

The molded wood specimens and rice hull moldings were submitted to an accelerated weathering test carried out in an Atlas Electric Weathermeter Model WVE. The samples were compared to commercial and industrial grade particle board (44 lb/ft^3 and 55 lb/ft^3 density respectively). The properties compared well, though the specimens were not intended for external use. Samples with mixed size particles showed the best surface condition after weathermeter testing.

Two flammability tests were performed on:

(a) industrial grade particle board (d=55lb/ft^3) (the control)
(b) molded rice hulls (YP-46);
(c) molded white pine (YP-58);
(d) molded ash (YP-64).

The flame spread test results showed that the molded rice hulls were the least flammable product. The industrial particle board was the most flammable of the samples, see Table 19. The molded wood samples were self-extinguishing. The smoke generated by the molded rice hulls was very low. Again, the particle board produced the most smoke.

Nail and screw retention tests of the wood waste moldings were conducted to determine material workability. The results were equivalent to those for industrial particle board. Rice hull moldings showed inferior nail and screw retention. A summary of all properties of the molded materials is found in Table 19.

The molded wood waste and rice hulls showed good mechanical properties without an external binder, when molded at pressures above 300 psi. A pressure of 500 psi gave the best results. It was felt that the addition of an external binder might reduce the need for high pressure. The binder should be reactive at low pH and be inexpensive.

Wood particles and rice hulls were soaked in a 10% aqueous solution of MF-115 (ITT Rayonier). The excess was decanted, the particles dried, soaked in 3% phosphoric acid and dried following removal of excess acid. The particles were molded at 150°C and 500 psi for five minutes. Both rice hulls and ash particles receiving the same treatment were dry and broke more easily than without addition of MF-115.

Soaking in a solution of Reylig-Al (ITT Rayonier) and 3% phosphoric acid was followed by molding at 150°C and 500 psi for five minutes. Though rice hulls showed 30% improvement in strength, when the molded specimens were put into water, they softened and were easily broken.

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II. Inorganic Matrix

The studies in this task involved two types of matrix and two kinds of composite. The two matrices considered were:

(a) an MBC inorganic matrix derived from magnesium oxychloride and sulfates;
(b) various classes of commercial plaster.

The MBC system is the more expensive matrix, but is stronger and more resistant to environmental effects. The plaster systems are more processable but must be protected from moisture.

Unlike the organic material, an elemental panel of an inorganic system does not offer a product. Instead, the materials had to be directed towards a functional application. Two applications suggested were the production of a high density structural composite defined as a laminate, and a low density core composite defined as a foam.

Laminate Development

Magnesium oxychloride was used in the MBC inorganic matrix. It has been used for floor construction and interior stucco surfaces for many years and MBC has previously studied its use as an efficient matrix.

The matrix was produced on MBC's continuous processing machinery. Glass fibers were used as the reinforcement. The material was deposited on a tray and allowed to "cure" at room temperature overnight. One half was covered with an impermeable Mylar film. The panel was then removed and permitted to continue its curing at room temperature for 28 days.

Figure 3 shows the tensile strength of the machine deposited laminate after testing at 6, 11, 18 and 28 days. The higher values for days 6 and 11 are questionable and may be attributed to test scatter. These results show that it is feasible to process the inorganic matrix continuously when a faster cure is developed.

A number of waste materials were tested as reinforcers. They included rice hulls, wood, Silvacon, paper, straw and cotton waste. The glass fibers were so superior to the wastes in performance that other reinforcements were disregarded. Systems, such as paper, which deteriorated when wet were completely unsatisfactory. Since the laminate is only part of the inorganic product, a limited utilization of an inexpensive commercially available material was considered consistent with the program study.

Studies conducted on the laminate

Figure 4 shows the effect of fiber length on strength. As can be seen, the longer the fiber the greater the strength. Two inches is the practical limit for processing. The superiority of a two-inch fiber is further demonstrated in Figure 5 which evaluates the effect of fiber content. Since the interfacial shear strength of the inorganic matrix is low compared to that of a polyester, a longer fiber would be expected to develop greater strength.

Figure 3 Tensile Strength of Machine Deposited Laminate

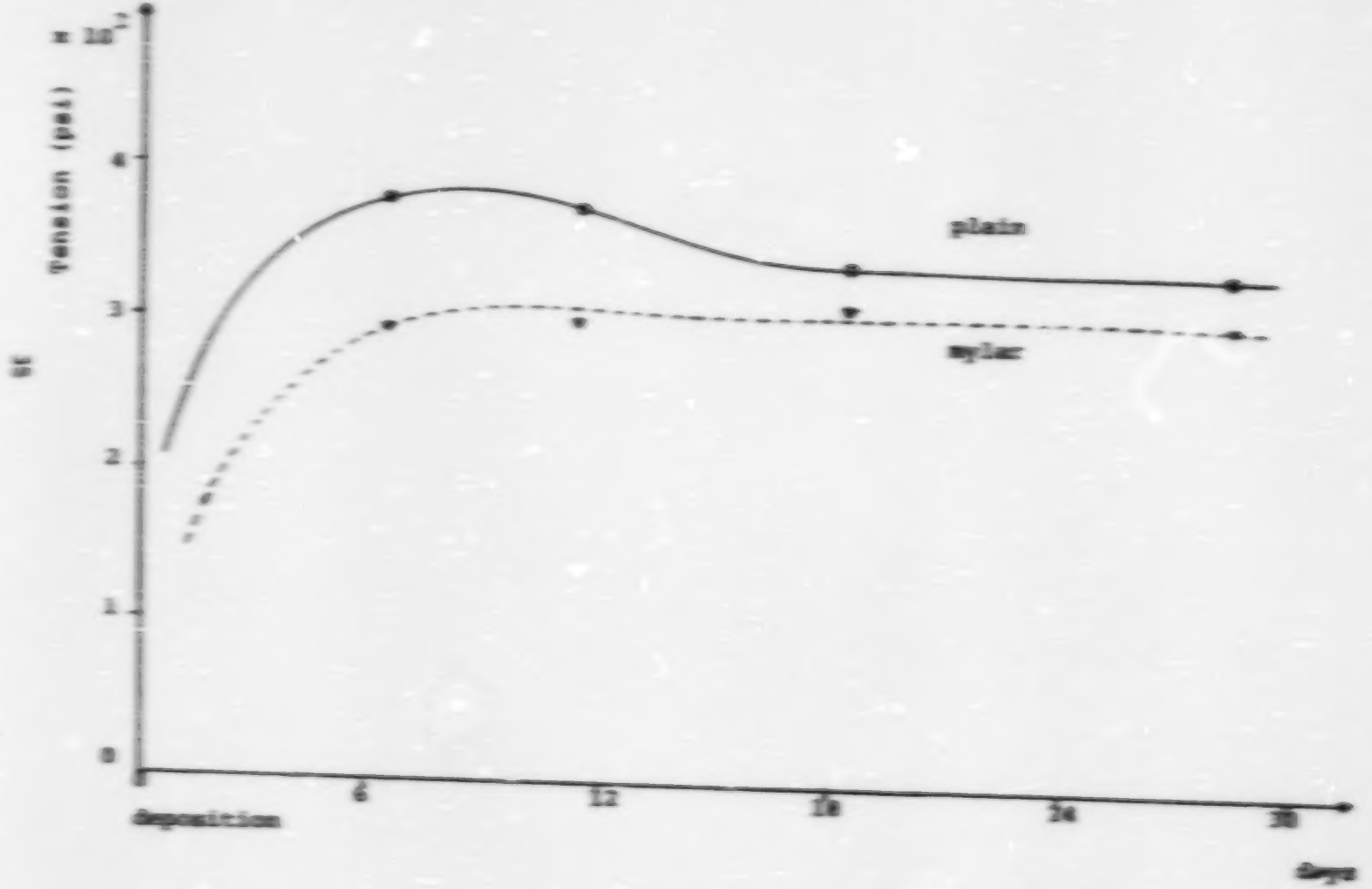
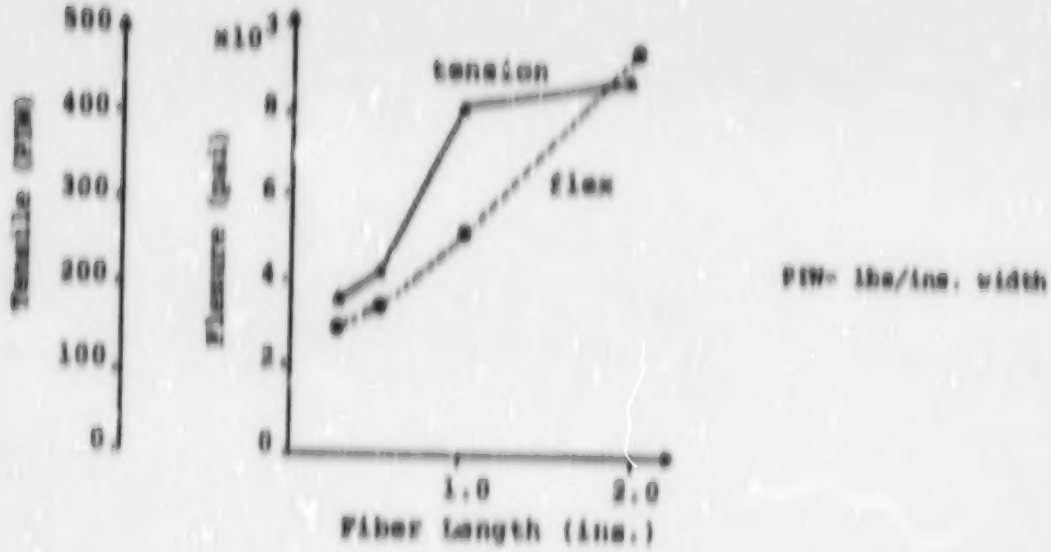


Figure 4 Effect of Fiber Length



PIW- lbs/ins. width

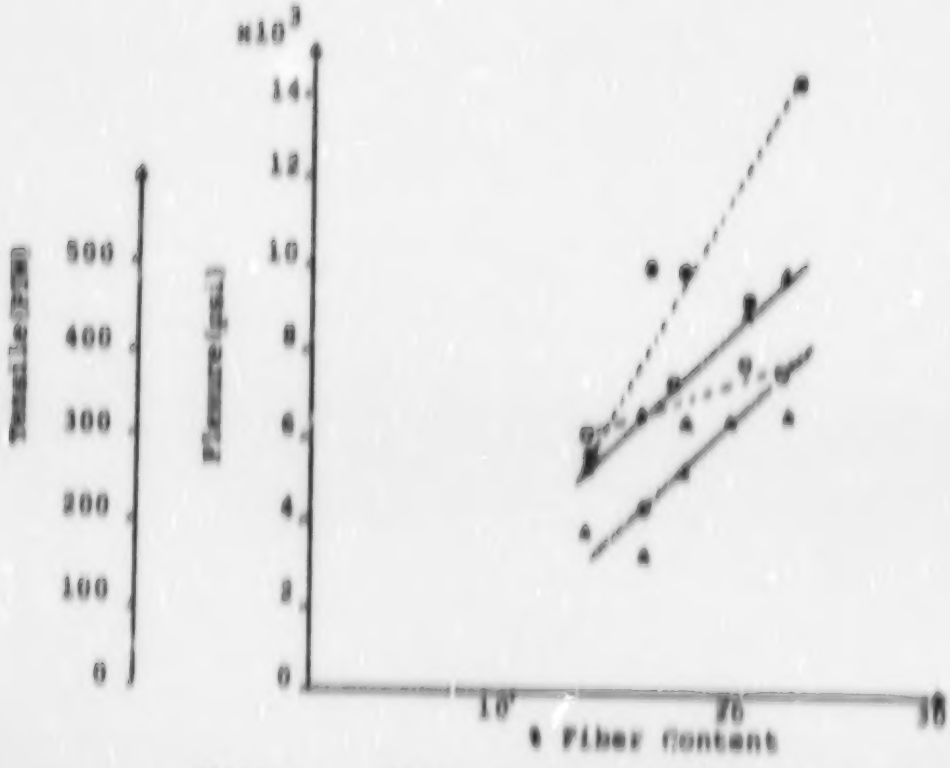


Figure 5 Effect of Glass Content and Fiber Length

[illegible]

[illegible]

[illegible]

The tensile values were recorded in pounds per inch of width. Thus, variance in thickness was not accounted for, resulting in the test matter shown. On an analytical basis, a higher fiber content should develop greater strength. However, under certain processing conditions and with certain matrices, a saturation point is developed where additional fibers provide limited improvement.

A number of other processing parameters were evaluated including the use of magnesium oxide and magnesium chloride from different sources. The results are summarized in Table 20. Bare glass "AR" appears to provide the best interfacial strength as a reinforcer.

The susceptibility of inorganic laminate fabrications to moisture was also evaluated. After water immersion, the laminate deteriorated in both strength and stiffness. In order to improve moisture resistance, a number of organic polymers were incorporated into the laminate. Addition of polyurethane resulted in the greatest improvement in moisture resistance.

Tests were also performed on surface seals; alkyd paint was most effective if maintained on the surface.

The relationship of tensile stress to strain for the inorganic laminate is shown in Figure 6. There is a clearly defined elastic region with a yield point followed by a very long plastic region. This type of characteristic is particularly good for building construction. If the yield point is exceeded, there exists a very long period of deformation before failure. This period permits corrective action to be taken before failure occurs.

In summary, these laminates demonstrate highly desirable building properties. In addition to strength, the laminate will neither burn nor smoke, it is inexpensive and the raw materials are freely available.

Foam Development

Initial studies focussed upon development of a medium density foam for use as a wood substitute. Desirable properties for the composite were considered to be non-flammability, lower cost than wood, and similar structural properties. Magnesium oxychloride and castlite plaster were used as the matrix while the fillers and reinforcers evaluated included rice hulls, cotton waste, scrap styrofoam, electrostatic precipitator fly ash, Silvacon 413 and 1/4" chopped glass. The electrostatic precipitator fly ash was supplied by the Environmental Protection Agency. Silvacon 413 is a Douglas fir bark fiber by-product, which has an interesting needle-like crystalline form and consists of almost equal parts of cellulose and lignin. The geometry of the Silvacon can contribute to toughening of brittle materials. Rice hulls are a voluminous filler with an apparent density of about 0.125 g/cm³ so that any material containing rice hulls will have this minimum density. Any additional material that will fill voids between the hulls serves to increase the apparent density.

Most construction systems use 2" x 4" wood profiles for door and window frames which can warp and pose problems. A substitute for these profiles must be light, inexpensive, non-warping and available. In order to test the reliability of the composites formulated, two reliability tests were performed: (a) the straight nail pull and (b) the bending nail pull. Composites successful in test (a) were also evaluated under test (b).

Table 21 gives the results of these tests for the various composites formulated. For all compositions, the rice hull reinforcement (dry fraction) and the binder/filler (wet fraction) were separately premixed. Wheat straw was evaluated as a replacement for the glass fiber reinforcement. As the straw proportion increased, mixing became more difficult, density was reduced by as much as 17% and nail retention reduced by up to 40%.

The effects on reliability of increasing the amounts of plaster and glass fibers were also evaluated. Increasing the plaster increased the density but had no effect on nail retention. Increased amounts of glass fibers reduced density and increased reliability but mixing became more difficult. Dry and wet mixing were carried out with a jiffy mixer causing no significant changes from hand-mixed materials. To overcome mixing difficulties, 1/4" glass fibers (with finish) were added and the density was reduced but with no increase in reliability. Tables 22, 23 and 24 summarize reliability data for various formulations.

In order to reduce process time, the effect of adding gypsum plaster to the casting plaster was evaluated. Introduction of as much as 15 parts of gypsum plaster caused hardening retardation of over two hours. Mixtures containing gypsum alone showed reduced reliability and density.

The materials tested were fire resistant and low in smoke generation, and would probably be good insulators of low density. Keeping this application in mind, a number of binders were evaluated against the following criteria:

(a) expense;
(b) efficiency in bonding;
(c) ability to disperse or emulsify in water;
(d) ability to harden on drying.

A number of matrix binders were tested including water glass, acrylic latex and wood bark extract. None of these binders was successful. Table 25 shows those compositions which showed structural integrity and would not ignite under a propane torch. These binders were prepared by blending the ABC proprietary binder with water, slowly adding the filler and blending for an extra minute. The mix was poured on rice hulls, mixed well, placed into a metal mesh mold and dried at 50°C or above. These compositions were subjected to the NBS smoke test (see Table 26) and a modified D-84 flame spread test (see Table 27). Both smoke density and flame spread test results showed very good fire resistance for these compositions. As they are also inexpensive and light, they seem to have good potential as insulation materials.

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

TABLE II

VARIABLE MATERIALS CONTAINING GYPSUM

(Parts by Weight)

Mix: Component	MX-38	MX-39	MX-40	MX-41	MX-42	MX-43	MX-44
Rice hulls	75	50	25	75	50	25	75
Wheat straw	25	50	45	25	50	75	25
Binder (MBC proprietary)	40	40	40	40	40	40	40
Casting plaster	200	200	200	300	300	300	150
Water	150	150	150	220	220	220	220
Fly ash							150
Density (g/cm³)	0.42	0.45	0.42	0.56	0.59	0.57	0.49
Density (lb./ft³)	26.3	28.2	26.6	35.4	36.8	35.8	30.9
Nail Retention*	13	13	17	24	24	33	13
Top	9	12	19	17	30	35	14
(lb.)	10	26	13	29	32	31	6
Average	10.6	17	16.3	23.3	28.6	33	14.3
Nail Retention							
Bottom	23	19	24	24	33	26	21
(lb.)	15	16	30	31	25	35	25
	11	32	40	25	37	24	22
Average	16.3	19.6	28	26.6	31.6	28.3	22.6

*Type I test, straight nail pull

TABLE 33

MATERIALS MATERIALS WITH INCREASED AMOUNTS OF CASTING PLASTER AND GLASS FIBERS

(Parts by Weight)

Mix:	MM-45	MM-46	MM-47	MM-48	MM-49	MM-50
Component						
Rice hulls	100	100	100	100	100	100
1" glass fibers (636 AR)	5	5	10	15	5	5
1/4" glass fibers (636 AR)					5	10
Binder (MBC proprietary)	40	40	40	40	40	40
Casting plaster	350	400	300	300	300	300
Water	230	260	200	200	200	200
Density (g/cm^3)	0.66	0.74	0.58	0.60	0.61	0.61
Density (lb/ft^3)	41.7	46.1	36.5	37.4	38.3	38.4
Nail Retention*						
Top	30	50	41	55	38	50
	45	45	43	70	30	52
(lb.)	34	40	33	90	30	36
Average	33	45	35.6	71.6	32.6	42.6
Bottom	95	35	50	62	31	38
	30	50	42	77	45	30
(lb.)						
Average	56.6	38.6	38.6	63	35	31

* Type 1 test: straight nail pull

TABLE 24

MATERIALS MATERIALS CONTAINING GYPSUM PLASTER

(Parts by Weight)

Mix: Component	MX-51	MX-52	MX-53	MX-54	MX-55
Rice hulls	100	100	100	100	100
1" glass fibers (A36AR)	15	15	15	15	15
Binder (MBC proprietary)	40	40	40	40	40
Gypsum plaster	300	150	75	60	45
Casting plaster		150	225	240	255
Water	300	200	200	225	225
Hardening time	hard but not dry after 20 hr. R.T.	same as MX-51	hard but not dry 3 hr. R.T.	hard & dry after 2 1/4 hr. R.T.	hard & dry after 2 hr. 10 min. at R.T.
Density (g/cm^3)	0.63	0.71	0.62	0.65	0.65
($lb./ft^3$)	39.1	44.5	38.7	40.9	40.5
Nail Retention*					
Top	34	45	55	51	44
	26	69	62	36	45
(lb.)	41	44	35	46	46
Average	30.3	52.6	50.6	41	45
Bottom	35	73	46	32	47
(lb.)	24	53	49	40	40
Average	26.6	55.3	44	41.6	41

* Type 1 test: straight nail pull

TABLE 35

COMPOSITIONS AND PROPERTIES OF RICE HULL INSULATING MATERIALS

(Parts by Weight)

Component	RH-8	RH-12
Composition		
Rice hulls	100	100
MOC prop. binder	40	40
Fly ash		800
Calcium carbonate	200	
Water	150	150
Density (g/cm³)	0.31	0.37
Compressive strength (psi)	c.s. 100	c.s. 100
Material costs ($/Ft³)	1.02	1.02

TABLE 36

NBS SMOKE DENSITY TEST RESULTS

Sample	RH-12	RH-12	RH-8	RH-8
Type of test:	Smoldering	Flaming	Smoldering	Flaming
Time to peak (min)	71	48	69	73
Time to smoke (D=16) (min)	1.5	3.7	3.0	1.6
Size of sample (in.)	3.84x3.74 x1.18	3.90x3.90 x1.34	3.9x3.8 x1.06	3.82x3.75 x1.10
Weight retention after test (%)	57	60	49	47

TABLE 27

FLAME SPREAD TEST RESULTS
FLAME FRONT LENGTH (in.)

Time (sec.)	1/8" Asbestos Cement	Nom. 1 in. Red Oak	MR-8	MR-8	MR-12	MR-12
20	5	10	9	9	7	7
40	5	12	8	8	7	8
60	5	13	8	8	7	8
80	5	14	8	8	7	8
100	5	14	8	8	7	8
120	5	14	8	8	7	8
140	5	16	8	8	7	8
160	5	16	8	8	7	8
180	5	19	8	8	8	8
200	5	19	7	7	8	8
220	5	19	7	7	8	8
240	5	19	7	7	8	8
260	5	19	7	7	8	7
280	5	19	7	7	8	7
300	5	19	7	7	8	7
Avg. maximum length (in.)	5	19	9	9	8	9
Flame number†	0	14	4	4	3	4
Flame spread ratings	0	100	28.5	28.5	21.5	28.5
Flame out time	0	2-3	0	0	0	0
After glow	0	4-5	0	0	0	0
Smoke color	none	white	white	white	white	white
Smoke quant.	none	medium	small	small	small	small
Smoke odor		wood	wood	wood	wood	wood
Temp. of sample‡ (°C)		not measured	50°	50°C	50°C	50°C

*Average maximum obtained from the three highest consecutive values recorded.
†Obtained by subtracting the maximum flame length of asbestos cement from the observed readings.
‡Temperature at back of the specimens (across from burner) right after test.

While the rice hulls were a cheap, satisfactory and plentiful filler/reinforcement for the composite, it was decided to test a number of other fillers. These included: magnesium chloride, magnesium oxide, calcium carbonate, fly ash, casting gypsum. Both fly ash and calcium carbonate seem to be good candidates for a fire-proof filler. Casting gypsum also appears satisfactory. Other insulating fillers tested were mineral rock wool, glass wool, vermiculite perlite and polystyrene foam beads.

Additional binders, fire proofing agents and reinforcements were studied as components for a fire-proof insulating material. Vinyl flat and water glass proved to be unsatisfactory binders while the MBC proprietary binder was most successful with a combination of rice hulls and inorganic fillers. Glass fibers and cotton waste were both considered as reinforcement. The 1" long glass fibers gave best results with the rice hull mixtures. Composites containing oil starch finished fibers out-performed composites containing silane finished fibers in strength and integrity. The cotton waste reinforced materials developed mold and presented mixing problems, though they showed improved strength and reliability. None of the fire proofing agents tested were compatible with the formulations.

In addition to the materials MB-12 and MB-8 previously discussed, three other compositions showed promise (see Table 38). Formulation MB-31 was developed further as a structural fire wall insulation.

A series of tests were performed on MB-31 material of thickness 0.5", 0.83" and 1.09" to determine the char depth, burn through and back temperature. Samples were placed vertically in a 4" x 4" gypsum board with a 2" x 2" hole in the center. A thermocouple was attached to the center by means of a steel strip. A propane torch with 1/4" nozzle was directed 5" away from the sample surface with gas pressure about 27 psi. The temperature was adjusted to 1600°F (871°C).

It was found that the insulation effect was not linear with thickness because the properties of the developing char were different from the non-burned material. There was a 100°F drop in temperature at the thermocouple placement (center of board) after the temperature peaked, attributable to the superior insulating properties of the char. This temperature peak was not reached by the 1" sample within a two hour period.

Weathering tests

While rice hull syntactic foams should not be exposed to outside conditions or high humidity, it was decided to evaluate the effect of adverse conditions on these materials.

The materials were soaked in water up to 7 days. Weight, compression strength and nail pull changes were checked. Accelerated weathering up to 400 hours was also carried out. Construction of the weathermeter chamber does not allow samples thicker than 1/2", so only weight changes could be measured. Water soak data (Table 39) showed a higher density material which means more plaster absorbed less water. MB-31 which included just fly ash

TABLE 28

RICE HULLS SYNTACTIC FOAMS

Material No.	RH-8	RH-12	RH-21	RH-31	RH-40
Rice hulls	100	100	100	100	100
1" Glass fibers			5	5	5
Proprietary binder	40	40	40	40	40
Calcium carbonate				300	400
Fly ash		200	200		
Water	150	150	130	200	260
Density (g/cm^3)	0.31	0.37	0.35	0.69	0.74
Nail withdrawal (lbs.)	0.31	0.37	0.35	0.69	0.74
Compressive strength (psi)	100	100	350	700	1300
Flame spread	28	24	24	12	7
Smoke density	72	48	48	15	10
Material cost ($/ft^3)	1.02	1.00	1.02	1.50	1.60

absorbed the highest amount of water.

Fly ash containing materials drastically lost their compression strength and nail pull resistance. Plaster-containing materials lost strength and suffered from lowered nail pull resistance but to a lesser extent. No significant difference was noted due to increased amount of plaster. Weather-ometer data showed weight loss, which indicated leaching out of either fly ash or casting plaster. After drying, the samples were firm and not warped.

It was also noted that mold growth can occur on rice hull syntactic foams. This required a study to find proper and effective fungicides to retard mold growth, possible water humid or wet conditions. The Buckman laboratories agreed to inoculate samples of the rice hull foams with species of fungi in order to test the efficacy of various fungicides. The fungi inoculated were: Penicillium roqueforti, Aspergillus niger, Chaetomium globosum and Aerobacter aerogenes. Untreated samples had a profuse growth of

naturally occurring Aspergillus sp. It was found that 0.6 to 1.0 parts by weight (with 100 parts rice hulls) of Busan 30-1 was very effective in retarding mold growth.

TABLE 29

WATER SOAK AND ACCELERATED WEATHERING DATA

Test	Material BH-21	BH-31	BH-46
Water Soak:			
Weight picked up (%)			
2 hr. soak	49	36	29
24 hr. soak	51	37	31
168 hr. soak	52	46	36
Compressive St. (psi)			
Control	350	700	1300
2 hr. soak	96	390	390
24 hr. soak	30	340	370
168 hr. soak	21	250	360
Nail pull (lb.)			
Control	18	43	45-70
2 hr. soak	6	19	16
24 hr. soak	4	27	25
168 hr. soak	3	22	30
Weathermeter:			
Weight Loss (%)			
200 hr.	3	9	12
400 hr.	6	21	19

Summary

There are a variety of inorganic matrix laminates and foams of waste materials which can be used competitively in the construction industry. The insulating material discussed above contains three major components:

(a) rice hulls as a filler/reinforcement;
(b) inorganic filler to add fire-proofing properties and act as a binder;
(c) matrix binder which may be inorganic or organic to hold the other components together.

Rice hulls make a good filler-reinforcement because of:

* low apparent density
* low cost
* rough surface easily texturable
* silica content lowers flammability
* abundant throughout the world.

The MBC purge/slurry inorganic binder was a successful matrix for combinations of rice hulls and inorganic fillers.

SECTION 5

PRODUCTS

ORGANIC MATRIX

Products which show the most promise for commercial development are:

(a) structural board
(b) replacement wheat rock
(c) lumber substitute
(d) fire doors.

(a) Structural Board

As can be seen in Table 30, organic materials show promise as a replacement for commercial grade particle board. It should be noted that each composite is presented in the density providing maximum strength but that densities vary in production in terms of modulus of rupture (MR). Most materials are of acceptable strength or are superior to the commercial particle board. The corn cob product, however, shows lower strength than the commercial board. The higher the modulus of rupture, the more desirable the product.

The flame spread and smoke generation criteria call for lower figures to demonstrate good qualities. As can be seen in Table 30, rice hull materials are far superior to commercial particle board; peanut shells, are nearly as promising as rice hulls.

Costs

Assuming that the waste material is converted into the product at the waste material source, comparative costs for rice hull materials, peanut shell materials, wood chips, and commercial particle board are shown in Table 31.

A complete economic analysis is given in Appendix C. Based on these figures, retail prices for the waste material based particle board would be 58% to 84% of that of commercial particle board.

In order to reduce shipping costs for waste materials, MSC had developed a process which reduces the bulk of the material by converting it to low density billets. In this process, the waste is treated with acid and then heated and dried. Through this process, shipping costs can be reduced from $0.014/lb to $0.005/lb.

| | | |

Table 30 (continued)

Material No.	55-26	55-56-C	55-62-C	55-63-C	55-64-C	55-30	55-126	55 lb/ft³ commercial grade
Composite Material	Rice hulls	Rice	Alder	Redwood	Ash	Corn cobs rice hulls	Peanut shells	Particle board
Water Soak:								
% weight gain	27	23	39	56	29	-	-	64
% thickness gain	13	13	21	11	9	-	25	22
Hardness:								
Before test	64	75	64	71	80	-	60	70
After test	55	40	36	63	50	-	40	50
Weatherometer Water (250 hrs.):								
% weight loss	17	10	20	17	10	-	-	26
% thickness gain	27	4	25	3	4	-	-	22
Hardness:								
Before test	62	70	65	75	70	-	-	--
After test	35	45	22	50	27	-	-	50

TABLE 31

COMPARATIVE COSTS OF PRODUCTS

	Rice Hulls	Peanut Shells	Wood Chips	Commercial Particle Bd.
Material cost	$0.632	$0.898	$0.861	$1.133
Cost to mfg. (1.67)*	1.055	1.501	1.471	1.797
Cost to retailer (1.25)*	1.318	1.876	1.838	2.246
Cost at retail (1.54)*	2.031	2.889	2.832	3.459

*For the three different elements in the manufacturing series, a built-in rule-of-thumb index was supplied by the manufacturer, i.e. for rice, the material cost is $0.632, the manufacturer buys it for 66% greater from the supplier (1.67 factor no.) which makes his cost $1.055 (0.632 x 0.67 $'s). The rule-of-thumb index from manufacturer to retailer is 1.25 (25% increase in cost); hence, cost to the retailer is $1.318 (1.055 x 1.25 $'s). The retailer takes his profit (54%), making the retail cost $2.031 (1.318 x 1.54 $'s).

This analysis of costs precludes consideration of labor and equipment amortization, which are assumed to be the same regardless of the material processed. Table 31 above indicates that waste material based panels can be produced at 35% to 68% of the cost of commercial particle board. If the cost of transportation within a 500 mile radius is included, then production costs would increase by 50 to 70% -- a factor which also applies to particle board manufacture.

(b) Sheet Rock Replacement

Sheet rock, dry wall or gypsum board are inexpensive and fire resistant, but highly susceptible to damage from impact or water. Fire tests were performed on a rice hull panel, peanut shell panel, commercial panel and sheet rock, for period of about 30 minutes, although times varied because of difficulties in controlling the fire. As a result, sheet rock was rated for 24 minutes, commercial particle board less than 20 minutes, rice hull materials for 27 minutes, and the peanut shell panel just less than 20 minutes. The commercial board burned most readily, and the peanut board began burning after 15 minutes. The rice hull panel did not smoke or burn. The rice hull panel was superior to sheet rock in performance, and was intact after the fire. Both the rice hull panel and the peanut shell panel were superior to the commercial particle board. It is believed that a commercial product with comparable properties to sheet rock could be manufactured from rice hulls.

Cost

A more complete analysis of cost may be found in Appendix C. Table II below compares the costs of materials made from peanut shell or rice hull composites with the costs of manufacturing sheet rock (Board size 1/2" thick, 4' x 8').

TABLE II

COMPARATIVE COSTS FOR SHEET ROCK SUBSTITUTES

	Rice Hulls	Peanut Shells	Sheet Rock
Material Cost	$0.519	$0.737	$0.500
Cost to Mfg. (1.67)*	0.867	1.231	0.848
Cost to Retailer (1.25)*	1.083	1.538	1.060
Cost at retail (1.56)*	1.668	2.369	1.632

* See explanation below Table II.

Rice hull sheets could be cost-competitive with sheet rock but peanut shell composites are more expensive. If, however, board of equivalent strength made from the three materials are compared rather than boards of the same size, then the rice hull panel appears even more economically competitive with the sheet rock. In order to make the comparisons below, the rice hull panel weight of 73 lb/cu ft. was compared to the 80 lb/ cu ft. of sheet rock and 50 lb/cu ft. of peanut shell panels.

	Rice Hulls (1/2")	Peanut Shells (1/2")	Sheet Rock (1/2")
Material Cost	$0.519	$0.503	$0.500
Cost to Mfg. (1.67)*	0.867	0.973	0.848
Cost to Retailer (1.25)*	1.083	1.217	1.060
Cost at Retail (1.56)*	1.668	1.874	1.632

*See explanation below Table II.

Screw and nail retention qualities of the organic panels are equivalent to sheet rock. The rice hull and peanut shell panels are more durable, more crack resistant and easier to work than the sheet rock. The greater flame resistance of the rice hull panels may give them a competitive edge over the slightly cheaper sheet rock panels.

(c) Lumber substitute

A third area in which the waste material panels may be competitive is as a substitute for lumber. Four qualities are important in this respect:

* equivalent strength
* equivalent nail and screw retention
* dimensional stability
* workability with carpenter type tools

Lumber substitutes are already being marketed at costs which are not particularly competitive with ordinary lumber. These substitutes have advantages in utilization of waste materials and in dimensional stability.

Tests with straight nail pull and straight screw pull indicated that the rice hull panel was inferior to the commercial panel and far below that of wood chip panels. All organic waste panels were easily workable with conventional carpentry tools.

In terms of costs, material for the 2" x 4" organic panel would be $0.037 per foot, retailing for $0.120 per foot -- compared to costs of conventional materials of $0.15, retailing for $0.20 per foot.

Despite cost advantages, more engineering development is required before the material can be considered as a lumber replacement. By redesigning the hardware of the plant, it should be possible to upgrade the panels to the quality of pine lumber or Douglas fir. This would require rethinking the design of performer, dryer, loading hoist, press and unloading hoist for a continuous feed process. Using 1967 cost figures, it is possible to estimate that the plant cost in 1975 dollars would be in the region of $4.5 million (see Appendix C)

The economic figures contained in Appendix C are based on production equipment not yet designed. In spite of assumptions it does appear that some product potential is indicated.

(d) Fire doors

Building standards require fire doors which will resist fire in excess of one hour. Based on an extrapolation from the previously reported data on 1/2" thick panels, blanks of 1 1/2" thick peanut shells, rice hulls or wood chips would withstand fire for two to three hours. A blank of any of the organic materials could be machined by routine door equipment, and hardware could be installed directly into the blank.

Cost

Assume a door requires 150 pounds of raw material; thus the material cost for a door is $1.67.

Assume present cure sales to retailer of $12 per door giving a cost differential of $.0.33.

Assume operational costs of $8,126 per day.

Breakeven production rate is then:

$$\text{Doors per day} = \frac{8,126}{10.33} = 806 \text{ doors.}$$

Assume a production rate of 2500 doors/day:

Generated Sales	$25,025
Operation cost	8,126
Profit	$17,499/day

This would generate yearly sales of $4,549,740. It is concluded therefore, that if a sufficient market is available for fire doors, that the organic panels would make an excellent product for commercial development. (These figures were based on the manufacturers own data and must be assumed to be based on reasonably accurate assumptions. There is no way to verify.)

From concept to market -- costs of product development

To this point there has been focus on the cost competitiveness of the four products discussed above. All are derived from waste materials and show varying degrees of potential at the market place.

For each of these four products, a further economic analysis has been performed to determine the cost of getting the product to the market place.

Four basic steps are involved for each material:
(1) design and qualification;
(2) development of manufacturing procedures;
(3) application of product to the market;
(4) acceptance of the product.

Table 33 below provides comparative figures for design and qualification costs for three separate products (panels, lumber substitute, and fire doors). Costs for the second product (lumber) are higher, due to the need for changing the production process from that used for similar products presently manufactured. Panels require the least change from present procedures, and this is reflected in the lower costs.

Table 34 below shows the comparative costs of development and manufacturing. Again the high cost of product development for the lumber substitute is clearly evidenced in comparison with the other two products.

Analysis of the practicality of developing the products entails consideration of physical properties of the material and its potential as a competi-

| | | |

TABLE 34

[illegible]

	Particle Board $	Lumber Substitute $	Fire Door Material $
Process technical services civil codes burden	-	43,680	-
Laboratory equipment	-	50,000	-
Material cost	-	500	-
Scale up technical services civil codes burden	6,720	43,680	6,720
Studies: process line purchase	12,000	475,000	12,000
Material costs	-	1,000	-
Pilot run technical services (includes burden)	13,440	43,680	6,720
Studies: additional line purchases		370,000	
Process line operation	60,000 (1500/hr)	60,000 (1000/hr)	30,000
Material costs	800	5,000	500
Start up product technical services includes burden	10,080	43,680	6,720
Need: Additional equipment		1,660,000	
Process line cost*	180,000 (1500/hr)	80,000 (1000/hr)	30,000
Material cost*	2,400	23,827	1,365
Cost	285,480	3,000,047	102,075
Multiplier (for normal problems)	(2.09)	(2.09)	(2.09)
Probable cost	596,674	6,270,098	213,336

* Assumes 75% of product is marketable

TABLE 15

PRODUCTS AND COMPOSITION

	Composition	Use	Material or Product Cost
I.	Rice hulls (100 parts) 1" long Fiberglass strands (15 parts) MOC proprietary binder (40 parts) casting plaster (240 parts) gypsum plaster (60 parts) water (225 parts) vanaldo PA germicide (.5 parts)	Wood substitute	.1¢/Ft, retailing at 9.1¢ commercial price is about 1/2 the price (lumber)
II.	Glass and plaster rice hull foam (.129 Ft³) inorganic glass pan (2.79 Ft²) adhesive (.079 lbs)	Fire rated partition walls: (a) Interior wall panels (b) Floor panels (c) Ceiling systems (d) Roof systems	9.87½/Ft² commercial two-hour fire rated wall: $1.79/Ft²
III.	Rice hulls (30 parts) casting plaster (90 parts) MOC proprietary binder (12 parts) water (66 parts) foamin (30 parts)	Fire door core	$1.791/Ft³ waste core: 88.71 commercial core: $12.00
IV.	Glass and plaster rice hull foam (.174 Ft³) inorganic glass pan (2.79 Ft²) adhesive (.0791 lbs)	Waste floor/ceiling	$1.061/Ft² commercial wood product: 1.624/Ft² commercial concrete product: $1.696/Ft²
V.	Rice hulls (100 parts) MOC proprietary binder (40 parts) Fly ash (200 parts) water (150 parts) Glass and gypsum	Ceiling panels	sale price: 80.15 to 80.39/Ft² commercial: 80.455 to 89.00/Ft²

tive product. This requires a market for the material and acceptance by potential users. Tasks involved in market development include the selection of a market and choice of methods of market penetration followed by actual marketing.

For the organic waste panels as a substitute for standard panels, marketing could be accomplished for a cost of $50,000 to $60,000. This product has a readily available market, and product acceptance should be easily accomplished. Competitive pricing would be the main impetus for purchase. The organic waste panel substitutes for sheet rock board will be more difficult to market due to higher price when compared with sheet rock. Market acceptance in this case must rest on superior performance. Marketing costs are estimated at $250,000.

Lumber substitutes will require proof of qualities comparable to lumber. Marketing should be through an existing distribution system, at a cost estimated at $125,000. Acceptance of this product will come through time. A subsidy is suggested as a means to encourage potential users to try the material. An estimate of a reasonable subsidy is $250,000. Thus to market this product, it may be necessary to invest $1.4 to $6.7 million. This sum could be recovered in one year if the market could sustain a 500,000 board feet per day production which is unlikely.

Fire doors will first read[illegible]ceptance in the market, since they would meet code approval at a very [illegible]petitive price. They could be distributed through an existing wood products distribution. The marketing cost is estimated at $50,000. Product acceptance can be assured by insuring that the product is the same as present products. Thus, to achieve a market, a cost of $169,825 to $294,576 is estimated, which could be recovered after one year of production.

INORGANIC MATERIALS

Five compositions were evaluated as potential products. As with the organic products previously discussed, economic viability of the product in a competitive market as well as mechanical acceptability were considered. The five compositions and product uses considered in this report are presented below.

(a) Lumber substitute for framing material

After a series of tests involving the evaluation of a 31" wide window panel and a 73" wide sliding glass door panel against building code standards, the wood substitute material was found to be below (CM) standards. Moreover, as can be seen from Table 15 above, products made from this material would not be cost competitive with lumber. Therefore, although the material is lightweight, reliable, and fire resistant, it was dropped from further consideration.

(b) Fire rated partition wall

Fire tests indicated a need for an all inorganic composite when the polyester inner skin of the tested wall material was found to soften and burn at high temperatures. The waste composite was compared to commercial products on flexure and impact tests. The panel tested performed much better than the previously qualified panels to which it was compared on stiffness. Costs of installation of the test panel were only 69% of conventional panels. Costs could further be reduced by lowering quality of the product or possibly by constructing the panel in one piece.

Fire tests showed that the panel was able to withstand flame for 1 hours with no smoke generation. As can be noted from Table 35, the partition wall is cost-competitive with commercial fire walls rated for two hour resistance. Fire smoke tests indicated superior qualities for the waste panel compared with the commercial product.

The same composite used in the fire rated partition wall could also be used for interior wall panels, floor systems, ceiling systems, roof systems and floor ceiling paneling. Interior wall panels could be produced for 76% of the cost of a standard 2" x 4" stud dry wall construction and would be a variation on the fire-rated partition wall.

Floor systems could be produced using the fire-rated panel finished with an attractive hard-wearing ceramic surface. The cost would be 74% of the cost for concrete slab and 53% of the cost of standard wood construction.

Self-supporting ceiling panels could be finished with a textured surface. The cost would be 69% of standard dry wall ceiling construction. The roof panel would require an impermeable seal as for any standard roof. The cost is 69% of standard wood construction.

All of these products would be fire-resistant and non-smoke generating. All could be prefabricated. Performance standards to be met are less stringent than for fire doors.

(c) Floor/ceiling system

A fire-resistant, non-smoking floor/ceiling panel was tested and found to be much stiffer than required for floor panels under current building codes. The floor/ceiling panels would be interlocking with end attachments designed for standard roofing or floor beam construction. Joints on both sides could be filled with an inorganic matrix of compatible texture. This system would cost 62% of the cost of standard wood construction and 59% of the concrete slab system. Moreover, the panel could be designed to fit over standard 2" x 4" sill plates; it is light (less than 200 pounds, allowing ease in handling) and the material can be easily cut with a standard carbide power saw. Like the other products made from this material, the panels can be prefinished at the factory. As can be seen in Table 35, the panels are cost competitive with the standard product.

The ceiling panel market is very competitive. The waste ceiling panels performed better on flame tests than the commercial product but their cost would be in the upper cost range for similar products already on the market. Therefore, it was not considered profitable to pursue this product further.

(d) Fire door core panels

Core panels of inorganic matrix/rice hull reinforcement 1 1/2" thick were faced with standard wood veneer surfaces and fire tested using standard techniques. Standard doors with areas of 2.33 ft^2 could be formed and sold at a price competitive with the current price. The cost was $8.71 for the waste core products, one with a thin inorganic glass facing under the veneer, and another covered only with veneer. Fire ratings were far superior to the standard commercial door (fire test times were 140 minutes, 130 minutes, and 78 minutes, respectively).

Costs

Design and qualification costs

Table 36 below shows the estimated costs for product design and for gaining qualification under existing building standards. Only three of the five main products were rated since the ceiling panel and the wood substitute did not show promise as marketable products.

Development and manufacturing procedures-costs

Table 37 gives the costs for the fire wall and the fire door core panels. The fire wall panels could be manufactured using standard concrete manufacturing equipment with some modification (not yet determined). Cost range is estimated from $79,600 to $144,076 depending on size of plant.

The fire door core could be manufactured using a modified plaster mixer with a continuous feed onto a conveyor of molds. Costs of the development of the manufacturing procedure is estimated to range from $82,753 to $49,782.

Marketing

Getting the product to the market involves selection of a market, evaluation of methods for market penetration, selection of a method of marketing, and actual marketing activities. The fire wall panel could probably be incorporated into the existing distribution system for such products. This procedure would cost an estimated $75,000. Gaining acceptance for the product should proceed through building contractors. A subsidy to encourage initial use is recommended at an estimated $250,000.

Marketing and product acceptance for the fire door cores is estimated at $38,160. A first step in design and qualification would be selection of an interested fire door manufacturer to construct a door with the core, which could then be qualified under building code requirements. Thus the remaining cost of marketing and gaining product acceptance is comparatively small. The cost of marketing the floor/ceiling panels would be similar to the costs for

TABLE 36

[illegible] AND QUALIFICATION COSTS INORGANIC PRODUCTS

	Fire wall	Fire door core	Floor/ceiling system
Technical services (includes burden)	$ 3,360	$ 3,360	$ 3,360
Mechanical test	5,000		3,000
Standard fire test	2,500	Fire Hose Test 4,000	5,000
Standard tunnel test (smoke and flame)	800	"	5,000
Materials	200	50	200
Tooling	1,000	100	1,000
Filing fees	570	570	570
Travel and support	1,000	1,000	1,000
Estimated cost	4,430	9,080	14,930
Multiplier (to account for normal problems [1.76])	(1.76)	(1.76)	(1.76)
Probable cost	$ 25,197	15,981	26,277

TABLE 37

DEVELOPMENT AND MANUFACTURING PROCEDURES - COSTS (HONEYCOMB PREFORMS)

	Fire Wall	Fire door core
Scale up studies:		
Technical services (includes burden)	$ 6,720	-
Equipment costs	6,000	-
Material cost	1,000	-
Pilot Run:		
Technical services (includes burden)	6,720	20,160
Equipment cost	6,000 (150/hr)	1,384 (94/hr)
Material cost	3,000	1,086
Start up and adjustment to product needs:		
Technical services (includes burden)	13,440	20,160
Equipment cost	6,000 (150/hr)	1,038 (94/hr)
Material cost	30,720	38,925
Estimated cost:	79,600	80,123
Multiplier (to account for normal problems (1.81))	(1.81)	(1.81)
Probable Cost:	$ 144,076	$ 149,782

the fire wall panels, i.e. an estimated $125,000.

Total costs

Taking into account the costs of design and qualification, development of manufacturing procedures, and marketing and gaining product acceptance, total costs for getting the products discussed above to market are:

Fire wall panel - A cost of from $419,030 to $494,473
Fire door core - A cost of from $139,991 to $201,921.

If the $13 sales price is maintained and the waste core cost is $0.71, a profit of $493,500 over costs can be extrapolated after the first year, assuming sales of 150,000 cores. For the floor/ceiling system a cost from $149,530 to $493,353 is estimated to get this product to market.

Summary

It is clear from the above discussion of products and costs that marketable building materials could be manufactured using waste materials. Satisfactory products could be made using both inorganic and organic systems. Often structural properties of the formulations were superior to existing commercial products. The economic analyses so far performed indicate that several products would be competitive at the market place - notably fire-retardant materials containing rice hulls (as either matrix or reinforcement).

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APPENDIX A

MATRIX SYSTEM CRITERIA

A. Matrix Candidates

1. Curability: Ambient temperature to 150° F — 5 pts
   151° F to 250° F — 4 pts
   251° F to 350° F — 3 pts
   351° F to 450° F — 2 pts
   451° F and up — 1 pt
   Noncurability — 0

2. Absence of Aroma:

   No odor in precursor component or final form — 5 pts
   Mild odor in precursor component and none in final form — 4 pts

3. Processability

   a. Time: Requires 2 to 10 minutes — 5 pts
   Requires 10 to 12 minutes — 4 pts
   Requires 12 to 14 minutes — 3 pts
   Requires 15 to 60 minutes — 2 pts
   Requires less than 2 minutes, more than 60 minutes — 1 pt

   b. Pressure: Roller, 0 to 15 psi — 5 pts
   16 to 25 psi — 4 pts
   26 to 50 psi — 3 pts
   51 to 100 psi — 2 pts
   Greater than 100 psi — 1 pt

   c. Temperature: Ambient to 150° F — 5 pts
   151° F to 250° F — 4 pts
   251° F to 350° F — 3 pts
   351° F to 450° F — 2 pts
   450° F and up — 1 pt

4. Physical Form: Liquid — 5 pts
   Soluble solid — 4 pts
   Insoluble solid but fusible below 350° F — 3 pts
   Insoluble solid but fusible below 500° F — 1 pt
   Unprocessable by our standards — 0

5. Toxicity:	Nontoxic	5 pts
	Noxious	3 pts
	Toxic	0
6. Decomposability:		
	Undecomposed to 600° F	5 pts
	Undecomposed to 500° F	4 pts
	Undecomposed to 500° F	3 pts
	Undecomposed to 400° F	2 pts
	Undecomposed below 400° F	1 pt
7. Color:	Absence of Color	3 pts
	Light Color	2 pts
	Dark Color	1 pt
	Black	0
8. Availability:	Available in useable state	10 pts
	Useable but in short supply	4 pts
	Raw material broadly available, collectable, process known	8 pts
	Raw material broadly available, collectable, process to be developed	7 pts
	Raw material broadly available, collection problems, process known	6 pts
	Raw material availability localized, collectable, process known	3 pts
	Raw material availability localized, collection problems, process known	1 pt
	Raw material availability localized, collection problems, to be developed.	0

B. Reinforcement Candidates

1. Mechanical properties

a. Tensile strength	100 psi and greater	5 pts
	50 psi to 99 psi	4 pts
	less than 50 psi	1 pt
b. Modulus:	5,000,000 psi and greater	5 pts
	1,000,000 psi to 1,999,999 psi	4 pts
	500,000 psi to 999,999 psi	3 pts
	less than 500,000 psi	1 pt
2. Surface to volume ratio:	High	5 pts
	Medium	3 pts
	Low	1 pt
3. Length to Width Ratio:	High	5 pts
	Medium	4 pts
	Low	2 pts

4. Absence of Aroma:	None	5 pts
	Mild	3 pts
	Strong	1 pt
	Stench	0
5. Availability:	Available in useable state	10 pts
	Useable but in short supply	4 pts
	New material broadly available, collectable, process known	8 pts
	New material broadly available, collectable, process to be developed	7 pts
	New material broadly available, collection problems, process known	6 pts
	New material broadly available, collection problems to be developed	5 pts
	New material availability localized, collectable, process known	3 pts
	New material availability localized, collectable, process to be developed	2 pts
	New material availability localized, collection problems, process known	1 pt
	New material availability localized, collection problems, process to be developed	0

C. Filler Candidates

1. Reactive to Matrix Material (In Destructive Sense)

Inert	5 pts
Very slow (requires at least 20 yrs)	4 pts
Slow (requires at least 15 years)	3 pts
Medium (requires at least 10 years)	2 pts
Rapid (requires at least 5 years)	1 pt

2. Decomposability:

Undecomposed to above 2000° F	5 pts
Undecomposed below 2000° F	4 pts
Undecomposed below 1500° F	3 pts
Undecomposed below 1000° F	2 pts
Undecomposed below 750° F	1 pt

3. Grindability:

200 mesh or better	5 pts
200 to 100 mesh	4 pts
100 to 100 mesh	4 pts
50 to 100 mesh	2 pts
Less than 50 mesh	1 pt

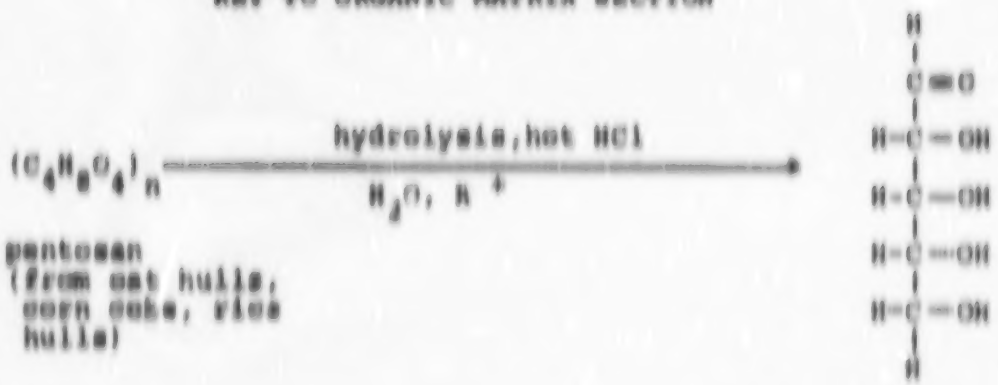
4. Density: Point value = 5 specific gravity

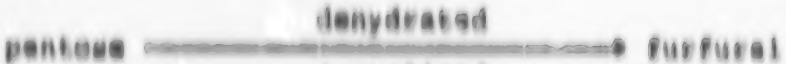
5. Absence of Arom:	None	5 pts
	Mild	3 pts
	Strong	1 pt
	Bland	0

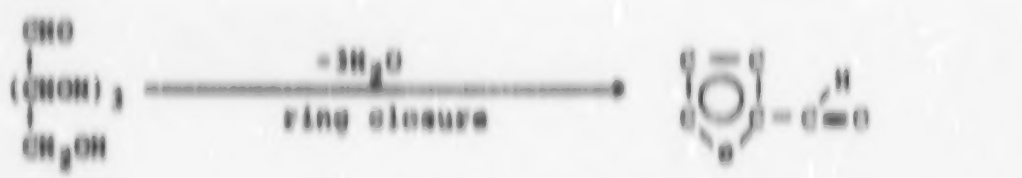
6. Availability:	Available in useable state	10 pts
	Useable but in short supply	4 pts
	Raw material broadly available, collectable, process known	8 pts
	Raw material broadly available, collectable, process to be developed	7 pts
	Raw material broadly available, collection problems, process known	6 pts
	Raw material broadly available, collection problems to be developed	5 pts
	Raw material availability localised, collectable, process known	3 pts
	Raw material availability localised, collectable, process to be developed	2 pts
	Raw material availability localised, collection problems, process known	1 pt
	Raw material availability localised, collection problems, to be developed	0

APPENDIX B

KEY TO ORGANIC MATRIX SECTION

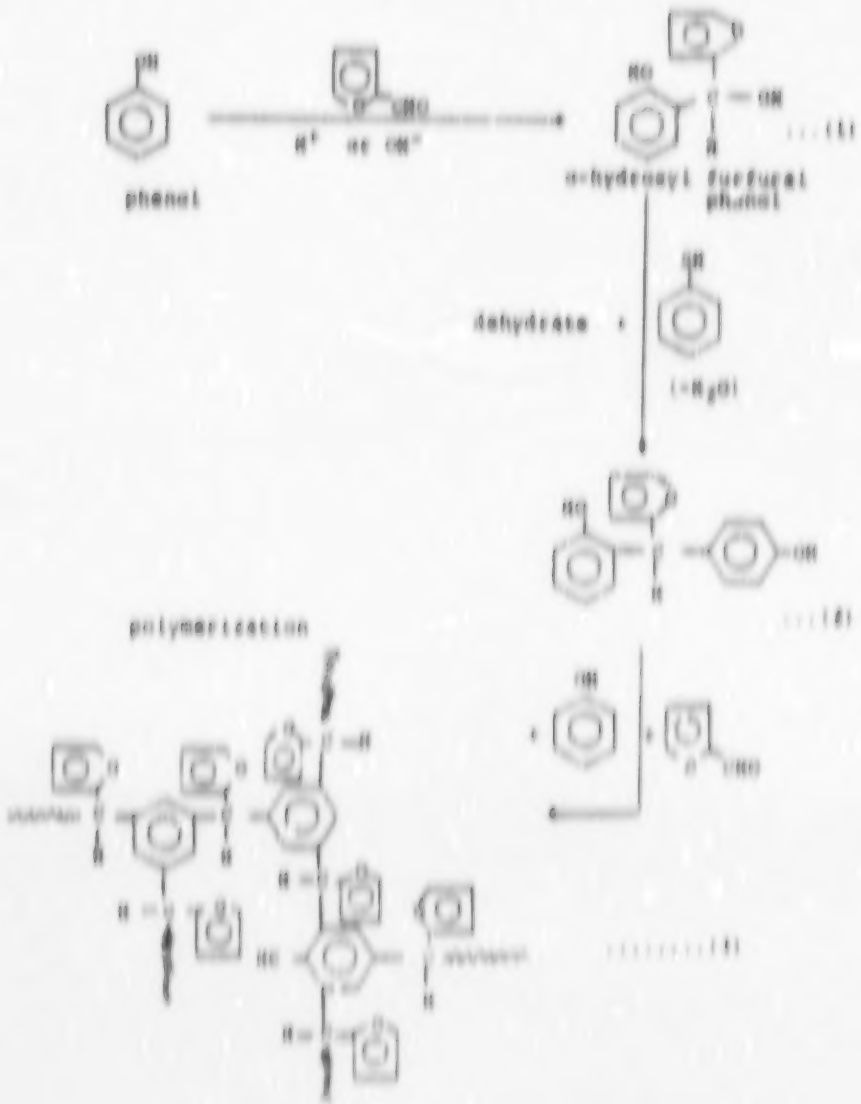






furfural
(2-furancarboxyaldehyde)

Phenol-Aldehyde Resin Reaction (Using Furfural)



Reaction 1: The phenol reacts with the furfural to form an ortho or para hydroxyl furfural phenol.

Reaction 2: The hydroxyl furfural phenol then reacts with another molecule of phenol, resulting in the loss of one molecule of water to form a compound in which the two rings are joined by a link.

Reaction 3: This process continues to yield a product of high molecular weight. Since these positions of each phenol molecule are susceptible to attack (namely the 2, 4 and 6 carbons of the two ortho and the one para positions,) the final product contains numerous cross-links and hence has a rigid structure.

APPENDIX C

COST ANALYSIS FOR COMMERCIAL PLANTS

1. Organic Matrix - Structural Board

Assume, plant cost of $8.27 million for production of 200 tons/day or 55 million sq. ft. of 1/2 inch board per annum at 45 lb/cubic foot density.

Assume material cost of $0.007/lb for rice hulls, $0.011/lb for peanut shells, $0.10/lb for wood chips.

Assume retail price of $0.03/lb, using commercial figures for particle board at 55 lb/cubic foot.

Assume first operation costs for plant capacity of:

Labor	$174,000/annum	
Other direct costs	292,600/annum	(not including material)
Indirect costs	281,800/annum	
Depreciation of 10%	827,000/annum	
Total costs/annum	$ 1,777,400	
Costs/day	6,836	

Break even production rate would be:

For rice hulls: $\frac{\text{cost}}{\text{retail diff}} = \frac{\$6.836/\text{day}}{.030/\text{lb}} \times \frac{\text{97 lb/ft}^3 \text{ Rice hulls}}{\text{55 lb/ft}^3 \text{ Commercial}} =$ 146,976 lbs/day.

For peanut shells:

$\frac{\text{cost}}{\text{retail diff}} = \frac{\$6.836/\text{day}}{.030/\text{lb}} \times \frac{\text{94 lb/ft}^3 \text{ Rice hulls}}{\text{55 lb/ft}^3 \text{ Commercial}} =$ 385,302 lbs/day.

For wood chips:

$\frac{\text{cost}}{\text{retail diff}} = \frac{\$6.836/\text{day}}{.031/\text{lb}} \times \frac{\text{94 lb/ft}^3 \text{ Rice hulls}}{\text{55 lb/ft}^3 \text{ Commercial}} =$ 372,873 lbs/day.

Assume full production. Facility costs are based on 200 tons/day of 45 lb/ft^3. The plant production is limited by volume, not density, i.e., more dense panels of 60 lb/ft^3 would mean production of 267 tons/day.

Profits would be as follows:

Rice hulls: 534,000 (.024) (55/67) = $10,920/day sales
- 8,236/day cost

2,684/day profit or

$2,684 (360 days) = $ 957,840/annum

Peanut shells: 534,000 (.020) (55/62) = $ 9,474/day sales
- 6,836/day cost

2,638/day profit or

$2,638 (360 days) = $ 685,680/annum

Wood shavings: 534,000 (.021) (55/63) = $ 9,790/day sales
- 6,836/day cost

2,954/day profit or

$2,954 (360 days) = $ 768,040/annum

Table 38 below gives the costs for commercial plants in comparison with rice hulls or peanut shell plants, using figures for 1967 and converting to particle board plant costs for 1975.

Estimated particle board plant cost in 1975 is $1.2 million plus $135,000 per million square feet of annual production. Therefore for a 200 ton per day plant (55 million sq. ft. annual production), the cost would be $1.2 million plus 55 times $135,000 or $10.6 million.

TABLE 38

COMPARISON OF CONVENTIONAL WOOD SHAVINGS PLANT
WITH A RICE HULL OR PEANUT SHELL PLANT

Conventional Wood Shaving Plant		Rice Hull or Peanut Shell Plant	
Unloading & storage	$ 120,000	Unloading & storage	$ 120,000
Milling & drying	190,000	Acid wash	100,000
Bonding & forming	690,000	Forming & drying	150,000
Press line	1,020,000	Press line	1,020,000
Finishing section	350,000	Finishing section	350,000
Auxiliary equipment	270,000	Auxiliary equipment	175,000
Total equipment cost	2,640,000	Total equipment cost	1,915,000

Production for Five Year Pay-Off

Cost per day $(8.27 \times 10^6)/5 \times 260) \div 6,836 = \$11,198$/day

Production required for:

Rice hulls: 13,198/.024 (62/55) = 669,898 lbs/day
= 335 tons/day
= 7,499 panels 1/2" x 4' x 8'/day
= 62 MM sq. ft. of 1/2" board/year

Peanut shells: 13,198/.020(62/55)= 734,869 lbs/day
= 367 tons/day
= 8,691 panels 1/2" x 4' x 8'/day
= 74 MM sq. ft. of 1/2" board/year

Wood shavings: 13,198/.021(62/55)= 719,890 lbs/day
= 360 tons/day
= 8,573 panels 1/2" x 4' x 8'/day
= 71 MM sq. ft. of 1/2" board/year

Conclusions

The developed waste process is a marginally viable venture. The break-even rate is 180 tons per day or 35 million square feet of 1/2" board/a year -- 1,093,750 panels, 4' x 8' per annum. Full production of 367 tons per day, or 79 million square feet of 1/2" board, or 2,481,624 4' x 8' panels per year would be required.

II. Organic matrix - lumber substitute

Based on the following 1967 figures, the estimated 1975 cost of manufacture for a similar facility is $4.5 million.

TABLE 19

ESTIMATE OF CONTINUOUS CHIPS FACILITY

Unloading and storage	120,000
Field wash	75,000
Performing into line	150,000
Press line - continuous	250,000
Finishing section	150,000
auxiliary equipment	100,000
	$ 845,000

Cost Analysis Assumptions

Assume the plant cost is $4.5 million.

Material cost is $0.055 per board foot (somewhat higher than MDC found).

Assume price to retailer is $0.195 per board foot (somewhat lower MDC figures).

Profit is $0.14 per board foot.

Operational costs as follows:

Labor	$420,000/annum
Maintenance & Operating supplies	275,000/annum
Indirect Costs	322,000/annum
Depreciation	450,000/annum
Cost per day	3,667

The break-even production would then be:
Board feet per day: 5642/.014 = 40,300, a sufficient amount of lumber for five (5) houses per day.

Assume full production of 500,000 board feet/day, then:
generated income = 500,000 ($0.14) = $70,000
3,667 in costs
daily profit = $66,333, a yearly income of $16,711,000

Assume that the lumber substitute can be marketed on a direct competitive basis.

Using these figures, and keeping in mind that the production equipment has not yet been designed, so that output can only be estimated, some product potential is indicated.

III. Organic matrix - Wheat rich substitute
Costs of production

Assume the plant cost is $8 million.

Assume material cost is $0.016 sq. ft. (rice hulls) and $0.010/sq. ft. (peanut shells).

Assume sales price to retailer is $0.033/sq. ft.

Generated differences are:
Rice hulls = $0.017/sq. ft.
peanut shells = $0.015 sq. ft.

The fixed operational costs are as follows:

Labor	$561,000 per year
Maint. & operational supplies	275,000 per year

Indirect costs ..... 420,000 per year
Depreciation ..... 600,000 per year
Total operational costs ..... 2,065,000 per year/260 days

Per day costs = $7,942.

Assume an additional 7% material cost added to all production. The breakeven production rate would then be:

Rice hulls: $\frac{7,942}{0.017 - (.007)(.017)}$ = 469 sq. ft./day

Peanut shells: $\frac{7,942}{0.015 - (.007)(.015)}$ = 533,020 sq. ft./day

Assume full production at 800,000 sq. ft./day, then the profit is as follows:

Rice hulls 800,000 sq. ft. (.017) = 13,600/day generated
- 7,942/day fixed cost
- 80/day variable cost
$ 5,578/day profit

Peanut shells 800,000 sq. ft. (.015) = 12,000/day generated
- 7,942/day fixed cost
- 80/day variable cost
$ 3,978/day profit

This would generate on a yearly basis:
Rice hulls: 5,578(260) = $1,450,280
Peanut shells: 3,978 (260) = $1,034,280

Those would require at the same price of about rice, 7 years to pay off the investment.